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A Series of Studies Examining the Development of Sprint Speed and Momentum of International Rugby Union Players

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USE OF THESIS

A Series of Studies Examining the Development of Sprint Speed and Momentum of International Rugby Union Players

PhD thesis

by

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DECLARATION

I certify that this thesis does not, to the best of my knowledge and belief:

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ABSTRACT

Sprinting speed is a highly valued physical ability in rugby. There is little research examining sprinting biomechanics in rugby players and it is unclear the extent that sprinting speed and sprint momentum can even be improved in highly trained rugby players and how different speed and strength training methods might help improve it. This thesis consists of 6 studies that examine the sprinting biomechanics of elite rugby players, how strength and power training might improve sprinting speed and the potential for elite rugby players to make further improvement in their sprinting speed and sprint momentum.

Key biomechanical factors were that as a player transitions from a standing start to maximal velocity; they do so without an appreciable change in stride rate but with a substantial increase in stride length. Stride rate remains the same because ground contact time and flight time are inversely proportional with each other as they accelerate from a standing start to maximal velocity. Faster players were found to have lower ground contact times and longer stride lengths for both acceleration and maximal velocity. Sprinting with a rugby ball in one hand did not seem to negatively affect international players in either acceleration phases or maximal velocity phases.

Mass was found to have a negative relationship with acceleration and maximal sprinting velocity. Sprint momentum, on the other hand, was found to have a strong positive relationship with body mass. Body mass and height were found to be higher in successful teams at the 2007 and 2011 Rugby World Cups when compared with less successful teams. Senior international players were found to have much greater sprint momentum and body mass, but not sprinting speed, when compared to junior players.

Collectively, all of these results point out that sprint momentum is a highly important physical quality. Sprinting speed is an important outcome of training programs but improving sprint momentum by increasing body mass is probably more important. The senior and junior athletes that were tracked for two years were able to effectively improve their sprinting speed and sprint momentum over a two year period which suggests that these are trainable qualities.

Strength and power were found to be important discriminators between fast and slow players. Faster players showed greater results in power clean, front squat, broad jump and triple broad jump. The relationships between these exercises and acceleration were similar for both the slow and fast groups but these exercises had much stronger correlations with maximal sprinting velocity in the slow group then with the fast group. The differences in these relationships seemed to be explained by ground contact time. The group of highly trained players that were tracked over a one year period did not show positive improvement in sprinting speed from increasing the different strength qualities. An 8 day hypergravity condition for international players was ineffective in producing profound changes in sprinting speed. These results suggest that sprinting speed is a trainable quality but there is a limited capacity for strength training to improve it once these qualities have been reasonably well developed in an elite population.

PRELUDE

This thesis by publication is presented as nine main chapters. The first chapter is a general introduction that outlines the aims of the thesis and the questions it aims to answer. The second chapter serves as a review of the literature pertaining to the physical development of rugby union players. Chapters three through eight examine different issues relating to the development of sprinting speed and sprint momentum of rugby players. Each of these chapters is a paper that has been published or accepted for publication in a peer reviewed scientific journal. The papers are presented exactly as accepted in the respective journals with the exception that the references, table legends, figure legends and section titles have been formatted to be consistent with the rest of the thesis. Chapter nine serves as a conclusion chapter and summarizes the major findings and practical applications of the thesis.

ACKNOWLEDGEMENTS

Completing this PhD thesis was a massive undertaking with many obstacles along the way that could have prevented me from successfully completing it. I have been fortunate to have many people help me navigate through those obstacles and I wish to acknowledge their contributions. Firstly, I must thank my principal supervisor Jeremy Sheppard for providing me with supportive guidance through this process. Working full time while completing a PhD is not an easy task but it is certainly much more manageable when you have a great research supervisor guiding you through it. I also need to thank my second supervisor Rob Newton for all of his help with the large amount of administrative steps that need to be taken when completing a PhD.

The completion of the research would not have been possible without the help of Dana Agar-Newman and Andy Evans who helped me train the Canadian national team players in these studies and were a large help in collecting in the data. The staff members at Rugby Canada were highly supportive so I must specifically recognize Kieran Crowley, Geraint John and Mike Shelley for allowing me to conduct my studies with their players. I owe a special debt of gratitude to Nadia Reider for all of her statistical help and proofreading but mostly for having patience with me while I was constantly travelling with rugby and working on my PhD during the evenings and weekends when I was finally back home.

Lastly, I must give large and heartfelt thanks to the Canadian national team rugby players that I worked with from 2009 to 2013 for participating in my studies. You represent all that is good about sport. If the powers of world rugby underestimate you, they do so at their own peril.

PUBLICATIONS ARISING FROM THE THESIS

Peer Reviewed Articles

Barr, Matthew J., Sheppard, Jeremy M., and Newton, Robert U., Sprinting kinematics of elite rugby players. *Journal of Australian Strength and Conditioning*, 21, 4, 14-20, 2013.

Barr, Matthew J., Sheppard, Jeremy M., Gabbett, Tim J., and Newton, Robert U., The effect of ball carrying in the sprinting speed of international rugby union players. *International Journal of Sport Science and Coaching,* In Press

Barr, Matthew J., Sheppard, Jeremy M., Gabbett, Tim J., and Newton, Robert U., Long-term training induced changes in sprinting speed and sprint momentum in elite rugby union players. *Journal of Strength and Conditioning Research*, In Press.

Barr, Matthew J., Sheppard, Jeremy M., and Newton, Robert U., Were height and mass related to performance at the 2007 and 2011 Rugby World Cups? *International Journal of Sport Science and Coaching*, In Press.

Barr, Matthew J., Sheppard, Jeremy M., Agar-Newman, Dana and Newton, Robert U., The transfer effect of strength and power training to the sprinting kinematics of elite rugby players. *Journal of Strength and Conditioning Research*, In Press.

Barr, Matthew J., Sheppard, Jeremy M., Gabbett, Tim and Newton, Robert U., The effect of 8 days of a hypergravity condition for improving the sprinting speed and lower body power of elite rugby players. *Journal of Strength and Conditioning Research*, In Review.

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Barr, Matthew J., Sheppard, Jeremy M., Gabbett, Tim J., and Newton, Robert U., Long-term training induced changes in sprinting speed and sprint momentum in elite rugby union players. *Journal of Strength and Conditioning Research*, 28, 10, 2724-2731, 2014.

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Barr, Matthew J., Gabbett, Tim J., Newton, Robert U. and Sheppard, Jeremy M., The effect of 8 days of a hypergravity condition on the sprinting speed and lower body power of elite rugby players. *Journal of Strength and Conditioning Research*, In Press.

I, *Matthew Barr*, contributed to the majority of work in the design, data collection, analysis and interpretation of the results, composition and editing of each of the manuscripts listed above.

Signed: Date: 19.05.2014

I, as a co-author, endorse that this level of contribution by the candidate indicated above is appropriate.

Jeremy Sheppard Date: 19.05.2014

Robert Newton Date: 19.05.2014

Tim Gabbett Date: 19.05.2014

Dana Agar-Newman Date: 19.05.2014

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
B1H	Ball in one hand
B2H	Ball in two hands
BM	Body mass
BMI	Body mass index
BJ	Broad jump
cm	Centimetres
CV	Coefficient of variation
d	Cohen's effect size
CMJ	Countermovement jumps
f/s	Frames per second
FS	Front squat
FS/BM	Front squat relative to body mass
GCT	Ground contact time
ISM	Initial Sprint Momentum
ISV	Initial Sprint Velocity
ICC	Interclass Correlation
IRB	International Rugby Board
ISAK	International Society for the Advancement of Kinanthropometry
kg	Kilograms
kg/m^2	Kilograms per meter per meter
kg*m/s	Kilograms per meters per second (momentum)
kg/kg	Mass lifted relative to body mass
MSM	Maximal Sprint Momentum
MSV	Maximal Sprint Velocity
m	Meters
m/s	Meters per second
N	Newtons
NB	No ball
P	P value
r	Pearson's correlation
PC	Power clean
PC/BM	Power clean relative to body mass
RWC	Rugby World Cup
s	Seconds
SWD	Smallest Worthwhile Difference
m/m	Stride length divided by height
strides/s	Strides per second
TBJ	Triple Broad Jump
TEM	Typical Error of Measurement

Chapter 1

General Introduction

1.1 – Thesis Rationale

Sprinting speed is a highly valued physical ability in rugby union (Duthie et al., 2006) and improving this physical quality is often one of the main foci of training programs (Duthie, 2006). There is very little research examining sprinting biomechanics in rugby players and designing training programs based on research done with untrained subjects or elite track and field athletes is not ideal. It is also unclear the extent that sprinting speed can even be improved in highly trained rugby players and how different speed and strength training methods might help improve it.

1.2 – Aims of the Thesis

The main research question of this thesis is to ascertain whether or not it is possible to substantially increase the sprinting speed and sprint momentum of highly trained international rugby players. In order to answer these questions three sub-questions need to be examined. The first is to examine whether or not rugby players' sprinting kinematics are similar to what has previously been reported for sprinters and untrained subjects or if they are unique. This is critical for developing proper testing protocols and designing effective programs. The second key sub-question is to determine whether or not improvements in leg strength and power lead to improvements in sprinting speed. The third question is to determine whether or not highly trained players keep improving sprinting speed and sprint momentum after several years of training. Each of these sub-questions is inter-connected and must be answered in order to answer them and the main question. An overview of all the questions that will be explored in the thesis and the connections between them is displayed in Figure 1.

Figure 1: Summary of the questions the thesis seeks to address and what chapters address those questions.

1.3 - Structure of the Thesis

This thesis is submitted in the form of a series of published research papers. The thesis examines:

- The sprinting kinematics of international rugby players (Chapters 3, 4, 5 and 7).
- How carrying a rugby ball affects the sprinting speed of international players (Chapter 4).
- How body mass affects sprinting speed and sprint momentum and the importance of those three physical qualities for rugby (Chapters 5, 6 and 7).
- How improving lower body strength qualities through strength and power training or simulated hypergravity might improve the sprinting speed of players (Chapters 7 and 8).
- We examine the long term potential of speed and strength training methods to positively improve the sprinting speed of highly trained rugby players (Chapters 5 and 7).

1.4 – Hypotheses of the Thesis

This thesis had the following hypotheses based on the research questions:

- International rugby players would hit their maximal sprinting velocity between 30 and 40 m.
- Players would hit their maximal sprinting velocity by increasing stride rate, increasing stride length and decreasing ground contact time.
- Senior international rugby players would be able to sprint while carrying a rugby ball at the same speed that they sprint without carrying a ball.

- Sprint momentum would be a key determinant of players being successful in reaching senior international rugby.
- Body mass and height would be a key determinant of success in international rugby.
- Sprint speed would be a trainable physical quality, even in senior international players with an extensive training background.
- Increasing lower body strength and power would contribute to players improving sprinting speed.
- A short term hypergravity intervention would improve lower body power and sprinting speed.

1.5 - Significance of the Research

Sprinting speed is a highly valued physical ability in rugby union (Duthie, 2006) and other football codes but it is a relatively understudied area given its importance. Developing a better understanding of sprinting biomechanics and the potential for different training methods to improve sprinting speed will make a meaningful contribution that will be usable by coaches around the world who work in rugby union or other similar sports.

Chapter 2

Physical Preparation of Rugby Union Players: An Overview

2.1 - Physical Preparation in Rugby

Physical preparation in rugby union presents a difficult challenge given the wide array of physical demands that are placed on players during the game. Optimizing physical abilities becomes a balancing act as players,. need to be prepared for large volumes of running and heavy physical contact while being proficient in a wide array of technical skills (Duthie, Pyne, & Hooper, 2003). Knowledge of exact physical requirements and optimal training methods becomes important because some of the desired training outcomes, such as mass and speed (Uth, 2005), or aerobic fitness and strength (Häkkinen et al., 2003), may actually negatively interfere with each other.

2.2 - The Importance of Speed in Rugby

A characteristic of modern elite rugby is the high volume of sprinting that takes place in games. Austin and colleagues (Austin, Gabbett, & Jenkins, 2011b) showed that, on average, professional rugby forwards in the southern hemisphere Super Rugby competition, on average, sprint just over 500 m in a game. Backs normally cover between 500 m and a 1000 m in a game. These figures are higher than that obtained in a similar study conducted in the same competition approximately a decade earlier (Duthie, Pyne, Marsh, et al., 2006). It has also been shown that speed over 10 m and 20 m has small to moderate correlations with the number of line breaks, tackle breaks, metres advanced and tries scored in professional rugby players (Smart, Hopkins, Quarrie, & Gill, 2014). This is consistent with earlier work that shows effective ball carries are related to executing at them at maximal possible sprinting speed (Sayers & Washington-King, 2003) as well as combining ball carries with evasive running patterns

(Sayers & Washington-King, 2003) and the use of an aggressive fend (Wheeler & Sayers, 2009). Almost all tackle breaks are a product of the attacker adopting strategies (fend, evasive running pattern, high running speed) to place the defender in a poor position to make the tackle (Wheeler & Sayers, 2009). This places pressure on the defender to have the agility and speed to cope with the strategies that the attacking player uses. This suggests that at least one component of being a good defender is sprinting ability. This concept has never been examined in rugby union; although it has been noted that there is a moderate correlation between tackling ability in rugby league and speed over 10m (Gabbett, Jenkins, & Abernethy, 2011).

A commonly asked question regarding speed in field sports is whether or not maximal speeds achieved in training are the same as achieved in games (Mendez-Villanueva, Buchheit, Simpson, Peltola, & Bourdon, 2011). Duthie and colleagues (Duthie, Pyne, Marsh, et al., 2006) showed the maximal velocities achieved in sprint testing were very similar to running speeds shown in game situations. One reason why it might be questioned whether or not rugby players hit maximal running velocity during the game is the fact that previous research showed amateur rugby players are slower while carrying a rugby ball when compared to running without a ball (Grant et al., 2003; Walsh, Young, Hill, Kittredge, & Horn, 2007) and this difference was more pronounced in university players who had just recently taken up the sport (Walsh et al., 2007). The implications of these findings are that to improve ball carrying ability it may be easier to improve the athlete's ability to sprint with the ball than to develop their ability to sprint faster without the ball. Conversely, one might argue that to best develop the ability to sprint, target and train this quality in relative isolation, and then

include subsequent training (with the ball) will manifest into higher sprint performances in the game of rugby itself. However, no one has ever examined the effect that carrying a rugby ball has on the sprinting speed of elite rugby players.

2.3 - The Importance of Size in Rugby

A notable trend over the 20th century in rugby has been the increase in the average size of players which exceeds the rate of normal population increases (Olds, 2001). The large number of heavy contact situations where the ball is contested certainly favours heavier players and it is likely a contributing factor to the size increase. The average number of tackles and rucks in games has dramatically increased since the mid-1990s when rugby became a professional sport (Quarrie & Hopkins, 2007). There also exists a strong correlation between the mass of an individual and the amount of force they can produce in a scrum (Quarrie & Wilson, 2000). The ability of a forward pack to combine heavy mass and a synchronized push is what produces large scrummaging forces (Quarrie & Wilson, 2000). The average number of scrums in rugby games has actually dropped over the years (Quarrie & Hopkins, 2007) but they remain a key aspect of the game. The amount of scrums lost has previously been shown to be a strong discriminator between winning and losing teams in the European Six Nations competition (Ortega, Villarejo, & Palao, 2009).

Height and mass are both noted to be higher in international level players when compared to amateur players (Holway & Garavaglia, 2009). The difference in mass is likely related to the advantage it provides in rucks, tackles and scrums. Differences in mass between professionals and amateurs are likely related to selection of larger players, and also by the large amount of time required to be dedicated to

strength training (Brooks, Fuller, Kemp, & Reddin, 2008), which is necessary for players to progress up to higher playing levels (Argus, Gill, & Keogh, 2011). The taller heights of international players may partially be explained by the fact that it is easier to carry more mass on a taller frame (Uth, 2005) but it likely is also related to aerial contests for the ball, particularly in the forwards. Lineouts lost is another area that discriminates between winning and losing teams in rugby (Ortega et al., 2009). Lineouts are an aerial battle between two jumpers, being lifted by two teammates each, 3 to 3.5 meters above the ground (Sayers, 2011). This would intuitively suggest that height is important but this has never specifically been examined previously. The actual influence that height and mass have on game outcomes and performances in competitions has not been examined in great depth. Sedeaud and colleagues (Sedeaud et al., 2012) examined the average mass and height of all teams participating in Rugby World Cups between 1987 and 2007. They found that on average, forwards and backs from teams that made the knockout rounds are taller and heavier than the teams that didn't advance. Given the rapid development in rugby over the past 15 years it is unclear whether the size advantage is still a contributing factor to success or whether that gap has closed between teams at the international level.

2.4 - The Relationship between Size and Speed

The importance of both speed and size in rugby presents a potential problem for rugby coaches. When examining historical data and body types of elite sprinters it would appear that there exists an optimal size for sprinters (Uth, 2005; Watts, Coleman, & Nevill, 2011; Weyand & Davis, 2005) that is not likely optimal for rugby players. It is likely that sprint momentum (Baker & Newton, 2008), which is calculated

from body mass and sprinting speed, is highly important in rugby union. The dimensions of the rugby field and the number of players on it likely dictate the body sizes necessary for play at the elite level. Typically, the average size of 7s rugby union players (Higham, Pyne, Anson, & Eddy, 2013) are much smaller than their average counterparts in the traditional 15-a-side version of rugby union (Duthie, Pyne, Hopkins, Livingstone, & Hooper, 2006). Having eight less players on the field and only three players in scrums removes the need for the massive forwards seen in normal rugby union games. The greater space on the field probably increases the opportunity for tackle breaks to happen as a product of speed rather than momentum (Sayers & Washington-King, 2003). Tackle breaks are important in both versions of the game (Higham, Hopkins, Pyne, & Anson, 2014; Ortega et al., 2009) but contact is likely less avoidable in 15-a-side rugby union than 7s rugby so line breaks must be achieved by dominating contact with momentum (Wheeler & Sayers, 2009). The mass that optimizes momentum may be different than the size that optimizes speed. Therefore, ball carrying momentum may be a more important factor in 15s rugby than ball carrying speed for achieving line breaks.

Sprinters are relatively the most massive of all running disciplines (Weyand & Davis, 2005) but the cluster of elite sprinters around certain masses and BMIs suggests that the ability to develop mass specific forces necessary for successful sprinting likely has a curve that peaks around athletes with a BMI of between 23 and 24 (Uth, 2005). Watts and colleagues (Watts et al., 2011) have noted a trend for elite sprinters to be more ectomorphic and tall than in years past. Rugby on the other hand, has seen a trend for players to become more mesomorphic in nature (Olds, 2001). Speed is a

more important ability to backs than forwards (Duthie, Pyne, Marsh, et al., 2006) and this is displayed in anthropometric data that shows that the average BMI is lower in back than forwards(Duthie, Pyne, Hopkins, et al., 2006). The BMI of professional rugby backs (Duthie, Pyne, Hopkins, et al., 2006) is still higher than sprinters (Uth, 2005), which suggest that it may be an optimisation that allows them to achieve high levels of both speed and ball carrying momentum, as ball carrying momentum has previously been found to discriminate between levels of players in professional rugby league (Baker & Newton, 2008). There is no literature regarding the influence of ball carrying momentum as a method of discriminating playing level in elite rugby union at present.

2.5 - Physical Development and Age

It has been shown in several studies that strength is a physical quality that remains trainable until at least the mid-twenties for rugby union (Appleby, Newton, & Cormie, 2012), rugby league (Baker, 2013) and American football players (Jacobson, Conchola, Glass, & Thompson, 2013; Miller, White, Kinley, Congleton, & Clark, 2002; Stodden & Galitski, 2010). There are only a few studies that have examined long term changes in sprinting speed and all were done with American football players. Sprinting speed was shown to be far less trainable in each of these studies with only very small, if any at all, improvements shown after the first year of university football (Jacobson et al., 2013; Miller et al., 2002; Stodden & Galitski, 2010). These results and the lack of studies examining speed changes in rugby union mean that it is unclear exactly how trainable speed is. An interesting but un-substantiated observation in international rugby is that props are typically the oldest players on the field. This is often attributed to the time it takes to master the technical ability of scrummaging. Conversely, it is

often observed, but also unsubstantiated, that wingers typically break into international rugby at a younger age than most other positions. A possible explanation is that it takes longer to master the technical abilities of scrummaging more so than any other skill set, but it is also possible that there are different time courses for the development of key physical abilities. Scrummaging is heavily dependent on absolute maximal strength (Quarrie & Wilson, 2000) which may take longer for an athlete to develop to their potential more so than sprinting speed. Olympic 100m sprint champions typically tend to peak at an earlier age than the running disciplines of longer distances (Schulz & Curnow, 1988) which shows that there does seem to be a difference in the development rate of different physical abilities. If speed development peaks at a younger age than maximal strength it might mean that props, who need high amounts of muscle mass and absolute maximal strength, may take a longer time to develop than wingers who depend on speed (Austin et al., 2011b) as their primary physical ability. Props require high amounts of muscle mass and strength because of their important role in the front row of a scrum. Wingers, on the other hand, typically have much more space and are valued for their open field running skills given their position usually places them in the backline on the edges of the field. If speed is not a highly trainable quality with elite populations then it would mean that talent identification would be more important than physical development for some positions.

2.6 - Trainable Elements of Sprinting

Given the importance of sprinting in rugby, it is important to maximize sprinting speed through technical training, strength/power development and specific sprint

training methods. There appears to be some biomechanical changes in sprinting technique that are necessary for athletes to achieve higher sprinting speeds.

2.6.1 - Acceleration Phase of Sprinting

The first few steps of a sprint from a standing start represent a highly coordinated activity where the athlete attempts to balance the forward rotation of their center of gravity while extending their hips and knees. Good technique, which maximizes horizontal velocity in the first few steps of a sprint, from a standing start is characterized by a large forward lean at toe off (Jacobs & van Ingen Schenau, 1992; Kugler & Janshen, 2010). However, if an athlete begins a sprint from a jog or as an athlete achieves higher velocities over their first few steps, the forward lean becomes less pronounced. An early training adaptation when athletes begin sprint training is an increased forward lean in their first two steps (Spinks, Murphy, Spinks, & Lockie, 2007). A kinematic difference between fast and slow field sport athletes was the amount of time that they spent on the ground over their first two steps (Murphy, Lockie, & Coutts, 2003). A similar, but not statistically significant, difference has been shown between elite and well trained sprinters in their 2nd step with no difference in the 1st step (Slawinski et al., 2010). However, the elite sprinters in that study were able to develop greater impulse in their ground contact times. The above studies suggest that learning to optimize the forward lean is an early training adaptation to acceleration training, minimizing ground contact time next and maximizing impulse as the final training adaptation.

As the athlete progresses past their first few steps, running kinematics start to resemble maximal velocity kinematics as acceleration begins to decrease and their

velocity gets closer to maximal (Volkov & Lapin, 1979). Athletes who achieve high sprinting speed between 8m and 18m do so by producing high levels of vertical and horizontal force and resultant impulse (Hunter, Marshall, & Mcnair, 2005; Kawamori, Nosaka, & Newton, 2013). It has never been investigated whether or not reductions in ground contact time accompany improvements in sprinting speed at this distance, but since reduced ground contact times coincide with increased maximal sprinting velocity (Rimmer & Sleivert, 2000) and speed improvement over the first few steps (Spinks et al., 2007) are accompanied by a decrease in ground contact time, this would be an expected training adaptation. Rimmer and Sleivert (2000) did find a small but non-significant decrease in ground contact time at the 7 m mark of a 40 m sprint following a plyometric intervention. The 10 m-20 m split was, however, the only 10 m split that did not improve so it does not discount that the mid-acceleration phase (roughly 5-20 m) is likely improved through a decrease in ground contact time.

2.6.2 - Maximal Velocity Phase of Sprinting

The achievement of maximal sprinting speed in athletes and how an athlete develops the forces to achieve this is an interesting area that has received some research attention. Mann and Herman (Mann & Herman, 1985) examined what produced higher sprinting velocities in Olympic 200 m sprinters and found that a key difference between medallists and an 8^{th} place finisher was a lower ground contact time. The lower ground contact times were produced by the foot making contact with the ground at a faster velocity and by a faster hip extension velocity. Kinetic analysis in sprinters showed that better sprinters use larger hip extension moments from ground

contact until the mid-support phase to produce higher sprinting velocities (Mann & Sprague, 1980; Mann, 1981).

Flight time and the ability to reposition legs during the sprinting stride appears to have no effect at all on sprint performance (Mann & Herman, 1985; Weyand, Sternlight, Bellizzi, & Wright, 2000). The time necessary to develop enough vertical impulse to raise the center of gravity to the necessary level and develop enough horizontal impulse to optimize stride length becomes the challenge to increasing sprinting speed (Mann, 2011). Faster running speed is achieved through briefer ground contact times which means that greater forces must be developed in a shorter period of time to maintain the necessary vertical and horizontal impulses (Weyand et al., 2000). Increases in maximal sprinting velocity have previously been shown to be a product of reduced ground contact time at maximal sprinting speeds (Majdell & Alexander, 1991; Rimmer & Sleivert, 2000). Training adaptations that allow this would likely be an increase in hip extension velocity and the ability to develop greater stiffness around the knee and ankle joint (Kuitunen, Komi, & Kyröläinen, 2002).

2.7 - Methods of Improving Sprinting Speed

2.7.1 - Strength, Power and Plyometric Training

The use of strength, power and plyometric exercises to improve sprinting speed is considered an essential part of the training process by most coaches. Moderate to strong correlations between sprinting ability in athletes and exercises such as squats relative to body mass (Baker & Nance, 1999; Barr & Nolte, 2011; Brechue, Mayhew, & Fontaine, 2010; Peterson, Alvar, & Rhea, 2006; Wisloff, Castagna, Helgerud, Jones, &

Hoff, 2004), cleans relative to body mass (Baker & Nance, 1999; Brechue et al., 2010; Hori et al., 2008), jerks relative to body mass (Brechue et al., 2010), unweighted and weighted countermovement jumps (Baker & Nance, 1999; Barr & Nolte, 2011; Berthoin, Dupont, Mary, & Gerbeaux, 2001; Brechue et al., 2010; Bret, Rahmani, Dufour, Messonnier, & Lacour, 2002; Hennessy & Kilty, 2001; Kale, Asci, Bayrak, & Acikada, 2009; Antti Mero, 1985; Nesser, Latin, Berg, & Prentice, 1996; Sleivert & Taingahue, 2004), broad jumps (Brechue et al., 2010), triple broad jumps (Brechue et al., 2010), and drop jumps (Barr & Nolte, 2011; Hennessy & Kilty, 2001; Kale et al., 2009; Mero, 1985) have been shown. Correlation does not equal causation though and an exercise or group of exercises can only be said to improve performance if an increase in performance of those exercises accompany an improvement in sprinting performance. The time course of adaptation from strength, power and plyometric exercises is also an important consideration as improvement in one exercise may not instantly transfer over to the targeted skill and there may be a delayed training effect.

Training studies done with non-athletes and physical education students typically show good improvement in sprinting speed after taking part in a training program that consisted of the above mentioned exercises. Tricoli and colleagues (Tricoli, Lamas, Carnevale, & Ugrinowitsch, 2005) showed an improvement in sprinting speed over 10 m, but not 30 m in a group of physical education students that followed a program of Olympic weightlifting. A group training in parallel but following a program of plyometrics showed no improvement. Another study (Delecluse et al., 1995) that compared a group undergoing heavy strength training and a group following a plyometrics program found that the group following the plyometric

program improved acceleration ability and maximal sprinting velocity and the heavy strength training group only improved acceleration ability. Plyometrics were shown to improve both acceleration and maximal velocity ability, but this finding was with non-athletic younger males (Kotzamanidis, 2006). However, a program of drop jumps compared with a program of machine strength exercises found that only the strength group made a significant improvement in 30 m sprint performance (Andrew, Kovaleski, Heitman, & Robinson, 2010).

There are several studies that have shown improvement in sprinting speed in developmental athletes. Studies that used only plyometrics have been shown to be effective in producing changes in both acceleration and maximal velocity ability in soccer (Chelly et al., 2010; Diallo, Dore, Duche, & van Praagh, 2001; Impellizzeri et al., 2008) and rugby players (Rimmer & Sleivert, 2000). A program that included only weighted jump squats has also been found to be effective at increasing sprinting ability in baseball players (McEvoy & Newton, 1998). Programs that were more comprehensive and included a combination of maximal strength training (squats, deadlifts etc.) and either power training (power cleans, weighted jumps etc.), or plyometrics (hops etc.), or all of the above showed improvement in sprinting ability (Hammett & Hey, 2003; Harris, Stone, Bryant, Proulx, & Johnson, 2000; Hoffman, Cooper, Wendell, & Kang, 2004; Kraemer, Ratamess, Volek, Mazzetti, & Gomez, 2000; Manolopoulos, Papadopoulos, & Kellis, 2006; Moore, Hickey, & Reiser, 2005; Myer, Ford, Palumbo, & Hewitt, 2005; Ratamess et al., 2007; Ross et al., 2009; Wong, Chamari, & Wisloff, 2010). Maximal strength training alone has shown improvements in sprinting abilities in some (Cressey, West, Tiberio, Kraemer, & Maresh, 2007;

Hermassi, Chelly, Tabka, & Shephard, 2011; Kotzamanidis, Chatzopoulos, Michailidis, Papaiakovou, & Patikas, 2005; Tsimahidis et al., 2010) but not all contexts (Harris et al., 2000; Hoffman et al., 2004; Mcbride, Triplett-McBride, Davie, & Newton, 2002).

Although a vast amount of research has been conducted with college-age individuals, only a handful of studies have investigated the outcomes of strength training interventions in elite or professional athletes. Ronnestad and colleagues (Ronnestad, Kvamme, Sunde, & Raastad, 2008) did not find an improvement in acceleration or maximal velocity ability in a group of professional soccer players that only incorporated squats into their training program. They did, however, find an improvement in maximal sprinting velocity in a group that combined squats and plyometrics. When they pooled the data of both groups, a statistically significant (Cohen's *d effect sizes* = 1.0 – 1.5, $P<0.05$) increase in both acceleration ability and maximal sprinting velocity was found. Improvements in speed over 5 m, 10 m and 20 m were found in a group of rugby league players after two months of combining speed, plyometric, and strength training including exercises such as squats, power cleans, clean pulls and RDLs (Comfort, Haigh, & Matthews, 2012). A large improvement in squat strength accompanied the improvement in speed so it is quite possible that the increase in strength and speed were related. Another study examining the effect of weighted jump squats and heavy strength training exercises (squats, deadlifts etc.) found an increase in 30 m sprint time in a group of professional rugby players (Randell, Cronin, Keogh, Gill, & Pedersen, 2011).

Studies examining long term changes in elite athletes are becoming more frequent (Appleby et al., 2012; Baker & Newton, 2006a; Hoffman, Ratamess, & Kang,

2011; Hunter, Hilyer, & Forster, 1993; Miller et al., 2002; Sheppard, Nolan, & Newton, 2012; Stodden & Galitski, 2010) although none so far have tracked the connection between speed and strength/power exercises. Reported changes in university level American football players seems to show little improvement in speed after the first year of training (Jacobson et al., 2013; Miller et al., 2002; Stodden & Galitski, 2010). It is unclear from the data in these studies if there is a relationship between improvements (or lack thereof) in strength/power and speed. Stodden and Galitski (Stodden & Galitski, 2010) reported that players only tended to make improvements in speed and vertical jump in their first year. Miller et al. (Miller et al., 2002) conducted another study of American university football players in which squat, bench press and clean continue to improve over time but neither speed nor vertical jump improved. It is unclear whether these studies point to a limit in speed and power development in highly-developed athletes or that physical preparation methods common in American football do not allow for continuous development. There is currently a gap in the literature regarding changes in strength/power exercises and how they correspond with changes in speed in elite athletes.

Bondarchuck (Bondarchuk, 2007) suggested that the more extensive the training background of the athlete the fewer the amount of exercises that will positively transfer to performance and the exercises that are least specific will reach a point of diminishing returns first. The implication for this is that maximal strength exercises like back squat may be the first to no longer have a positive training effect. Comfort et al. (Comfort, Bullock, & Pearson, 2012) noted that there was a strong relationship between squat strength and acceleration ability while sprinting when

examining a group of participants that ranged from recreationally trained participants to athletes. When the groups were examined separately the recreationally trained men still had a significant correlation between squat strength and sprint performance, but this was not observed in the group of athletes. A training program with American football players that resulted in large improvements in the power clean and back squat was found to positively affect vertical jump yet negatively affect sprinting speed (Moore & Fry, 2007). It is possible that many training programs devote too much emphasis on exercises that have ceased to be an effective method of increasing sprint performance for the athletes using them. In other words, general strength and power exercises that have previously provided significant transfer to sport performance in developing athletes may provide little appreciable additional benefit to the sporting performance, despite the now elite athlete still making gains in the general exercise. An exercise such as back squat may be effective at helping improve the sprinting speed of a lowly trained athlete because producing larger force is important for achieving high velocities while sprinting (Peterson et al., 2006). Sprinting involves producing high vertical forces very briefly (Weyand, Sandell, Prime, & Bundle, 2010) though and involve large eccentric loads (Mero & Komi, 1994) so it may not be specific enough to improve sprinting speed if it is the only lower body exercise. One worthwhile way to examine this would be to longitudinally track a group of athletes and see if the changes in strength and power (squats, cleans, jumps etc.) corresponded with changes in sprinting ability.

2.7.2 - Overspeed and Overload Methods

An interesting phenomenon that seems to be effective across any sporting skill, that involves an attempt to maximize speed of movement and is brief in nature, is the manipulation of the external load limiting movement that is limiting the speed of movement. This is done so that the movement can be done faster than normal. This "overspeed" method has been effective for improving performance in throwing handballs (Gorostiaga, Izquierdo, Iturralde, Ruesta, & Ibáñez, 1999; Skoufas, Stefandis, Michaildis, Hatzikotoulas, & Kotzamanidou, 2003; van Muijen, Joris, Kemper, & van Ingen Schenau, 1991), baseball pitching (DeRenne, Ho, & Murphy, 2001), cricket bowling (Petersen, Wilson, & Hopkins, 2004), vertical jumping (Argus, Gill, Keogh, Blazevich, & Hopkins, 2011; Sheppard et al., 2011), martial arts kicking (Jakubiak & Saunders, 2008), swinging a baseball bat (DeRenne, Buxton, Hetzler, & Ho, 1995), and sprinting (Majdell & Alexander, 1991; Paradisis & Cooke, 2006; Upton, 2011). An "overload" method has also been shown to be effective throwing handballs (Gorostiaga et al., 1999), baseball pitching (DeRenne et al., 2001), cricket bowling (Petersen et al., 2004), vertical jumping (Argus, Gill, Keogh, et al., 2011; Khilfia et al., 2010; Lyttle, Wilson, & Ostrowski, 1996; Marques, van den Tillaar, Vescovi, & Gonzalez-Badillo, 2008; Newton, Rogers, Volek, Hakkinen, & Kraemer, 2006; Randell et al., 2011; Wong et al., 2010), swinging a baseball bat (DeRenne et al., 1995), and sprinting (Harrison & Bourke, 2009; Myer, Ford, Brent, Divine, & Hewett, 2007; Paradisis & Cooke, 2006; R. Ross et al., 2009; Spinks et al., 2007; Upton, 2011; D. J. West et al., 2012). Many of the above mentioned studies also combined the two methods together. The critical component with these methods is determining the force that is being overcome and understanding how to manipulate it. Ball throwing is relatively simple since the inertia of the ball is the major force being overcome and can

be manipulated by throwing lighter balls, heavier balls or by weighting the wrist. Vertical jumping is also relatively simple as it can be done in "overspeed" manner by attaching elastic bands to the jumper to de-load them (Sheppard et al., 2011) and the "overload" method (Cormie, McGuigan, & Newton, 2010) can be done with dumbells, barbells or weighted vests .

The overload method for sprinting can be done by wearing a weighted vest for maximal velocity sprinting (Clark, Stearne, Walts, & Miller, 2010). Pulling a sled during acceleration is also effective (Harrison & Bourke, 2009; West et al., 2012) since the line of pull of the sled to the harness is similar to the resultant force vector produced by the athlete in his first few steps (Kugler & Janshen, 2010). Uphill sprinting which has also been shown to be effective (Paradisis & Cooke, 2006; Paradisis, Bissas, & Cooke, 2009) likely adds an overload by increasing the vertical impulse necessary to raise the athletes center of gravity over each stride.

Overspeed sprinting is usually attempted by towing the athlete or having them sprint downhill. Sprinting downhill likely allows for less force than is needed in flat ground sprinting to be developed in a vertical direction so that more force can be exerted in a horizontal direction allowing for faster running speeds (Ebben, Davies, & Clewin, 2008) and appears to be effective as a training method (Paradisis & Cooke, 2006; Paradisis et al., 2009). Overspeed sprinting by towing also seems to be an effective way to improve sprinting speed (Kristensen, van den Tillaar, & Ettema, 2006; Majdell & Alexander, 1991; Upton, 2011). This method does not actually reduce the load that has to be overcome (gravity) but does expose the athlete to higher eccentric loads and increased muscle activation (Mero, Komi, Rusko, & Hirvonen, 1987; Antti

Mero & Komi, 1987) which may lead to important training adaptations. The athlete's increased speed is caused by increasing stride length and an increased flight time (Corn & Knudson, 2003; Leblanc & Gervais, 2004; Mero et al., 1987; Antti Mero & Komi, 1985) and sometimes through a decrease in ground contact time (Leblanc & Gervais, 2004; Mero & Komi, 1985). A decrease in ground contact time through an increase in net propulsive impulse is the key biomechanical factor by which athletes increase stride rate and maximal sprinting velocity (Kristensen et al., 2006; Rimmer & Sleivert, 2000).

2.7.3 - Chronic Hypergravity Method

The traditional paradigm for improving athletic performance is conducting a series of training sessions which contain drills and exercises that are specific to the sporting skill. The cumulative effect of all of the *acute* training stresses from each training sessions leads to an adaptation and an improvement in performance. An interesting method that has previously been tested involves a *chronic* non-specific non-training stress that leads to an improvement in performance. Bosco and colleagues (Bosco et al., 1984) first demonstrated that by having elite jumpers and throwers wear a weighted vest 13% of the athletes body mass, to simulate the athlete being exposed to "hypergravity", for 3 weeks led to an enhancement in jumping ability of approximately 2-4 cm during body weight jumps, jumps with 10-40 kg additional load and drop jumps. Interestingly, the training adaptation appeared to have completely dissipated after 4 weeks. A 2nd study by Bosco and colleagues (Bosco, 1985) showed an average increase of 5cm in countermovement and drop jumps after wearing a vest weighing 11% of body mass for 3 weeks. What was particularly

interesting about the groups of track and field jumpers involved in the intervention was that they had not made any improvements in jumping ability in the previous year. A third investigation by Bosco and colleagues (Bosco, Rusko, & Hirvonen, 1986) used another three week intervention but this time with sprinters wearing vests weighing 7-8% of body mass. A similar result was found again with a 3 cm increase in countermovement jump after 3 weeks of wearing a weighted vest.

The value of chronic hypergravity was further verified by Sands and colleagues (Sands et al., 1996) who found a similar improvement in vertical jump performance in collegiate track and field athletes. The authors additionally noted that every individual was successful in achieving multiple personal bests in the following competition period. A few interesting aspects of the above mentioned study was that they used a periodized approach with vest weights progressing from 8%, 10% and finally 12% over the three weeks of the study. In addition, 4 members of the experimental group developed shin splints during the study and had to stop wearing the vest during training, but continued to wear the vest at all other times of the day. The fact that the athletes could still make improvement from the intervention without wearing them during training is an important consideration for a contact team sport like rugby, where it would be impractical and potentially dangerous to wear the vest during training. Another interesting aspect of that study was that they tested weekly during the intervention and it appears that the adaptation stabilized sometime between 7 and 14 days, and was maintained for around 2 weeks after the intervention. This would present the possibility of having athletes wear the vests for a shorter period of 1

to 2 weeks and not wear the vests during training. This would make it possible to utilize the weighted vest intervention in a contact sport like rugby.

One key omission from all of the previous studies was that they did not measure changes in sprinting speed during any of these training studies. Vertical jumping ability usually correlates highly with sprinting ability (Barr & Nolte, 2011; Brechue et al., 2010; J. Cronin & Hansen, 2005; Hennessy & Kilty, 2001; Kale et al., 2009; Nesser et al., 1996) but any improvement in vertical jumping ability does not mean an immediate carryover to sprinting speed. If such a method was successful in improving sprinting speed, it could be a powerful training tool for improving speed in athletes who have a long history of maximal strength and power training, and whose performance has plateaued . It would be difficult to use this method in the middle of a rugby competition where there are weekly games. However, this could be an effective method in rugby if it could be used for a shorter period of time where breaks in the competition schedule would allow for 7 to 10 consecutive days of this intervention.

Chapter 3

Sprinting Kinematics of Elite Rugby Players

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3.1 ABSTRACT

The purpose of this study was to characterize the sprinting kinematics of elite rugby players as they transition from a standing start to maximal velocity. A group of players (n=11) underwent an assessment of their sprinting ability by performing four 50 m sprints. All players (height = 1.86 ± 0.08 m, mass = 100 ± 9 kg) had played senior international rugby. Each of the sprints was filmed using Nikon J1 video cameras recording at 400 f/s at the 3 m, 9 m, 15 m, 21 m, 27 m, 33 m, 39 m, and 45 m marks of the 50 m sprints. Stride length, stride rate, ground contact time, flight time and velocity were calculated using a computer program (Kinovea). Velocity peaked at either the 33 m or 39 m mark with significant differences in velocity between the 33 m mark and velocities at 3 m, 9 m and 15 m marks ($P<0.05$ - $P<0.0001$). Ground contact time at the 3 m mark was significantly longer than at every other distance measured ($P<0.0001$). Stride length was significantly shorter at the 3 m ($P<0.0001$) than every other section. Stride length and ground contact time at 9 m were significantly different from every other distance except for 15 m. No differences were found in stride rate between any of the distances. Elite rugby players achieve their top speed between 30 m and 40 m and do so by decreasing ground contact time and increasing stride length as they accelerate.

Key Words: Speed, Maximal Velocity, Ground Contact Time, Stride Rate, Stride Length

3.2 INTRODUCTION

Sprinting speed is considered to be an important physical ability for rugby players (Sayers & Washington-King, 2003; Smart et al., 2014). Speed is often considered to be just one single physical quality and athletes are often evaluated by their time to complete a sprint of a given distance (ie 40 m). However, sprinting ability could be considered to be several different physical qualities, as long sprints are considered to consist of several different phases. Definitions vary, but typically involve one or more acceleration phases and a maximal velocity phase (Brown, Vescovi, & Vanheest, 2004; Mann, 2011; Tricoli et al., 2005). Acceleration is often considered highly important for rugby because of the high number of sprints done over a short distance during games (Austin et al., 2011b). Maximal velocity is also considered important as rugby players frequently hit their maximal sprinting velocity during games (Duthie, Pyne, Marsh, et al., 2006), and in field running sports, sprint bouts are often initiated from a moving start such that athletes can achieve top speed in a relatively short period of time (Benton, 2001).

The distinction between different sprint phases is important as each phase has kinematic differences (Debaere, Jonkers, & Delecluse, 2013; Kugler & Janshen, 2010; Weyand & Davis, 2005) and needs to be approached differently when coaching technique and designing training programs to improve them. Training programs for rugby players, however, should be based on what is typical of elite rugby players rather than what is typical of elite sprinters as there likely are differences between the two. For instance, the reported distance that athletes attain maximal velocity at ranges between 50-60 m in elite sprinters (Gajer, Thepaut-Mathieu, & Lehenaff, 1999),

30-40 m in national level sprinters (Chengzhi, 1991), 30-40 m in physical education students (Babić, Čoh, & Dizdar, 2011) , 30-40 m in adolescent sprinters and 20-30 m in pre-pubescent sprinters (Papaiakovou, 2012). It is currently unknown at what distance rugby players transition into a maximal velocity phase or at what distance maximal velocity occurs. It is also unclear how kinematic variables such as velocity, stride rate, stride length, ground contact and flight time change as elite rugby players accelerate up to maximal velocity.

The aim of this study was to characterize the sprinting kinematics of elite rugby players as they transition from a standing start to maximal velocity. It was hypothesized that rugby players would achieve maximal velocity between 30 m and 40 m. It was hypothesized that rugby players would achieve their maximal velocity in this range because of similar distance-velocity profiles in sub-elite sprinters.

3.3 METHODS

3.3.1 Approach to the Problem

In order to characterize sprinting kinematics of elite rugby players, a cross sectional experimental design was used. The subjects participating in the study underwent a series of sprints that were filmed with high speed video cameras in order to determine changes in their sprinting kinematics as they accelerated up to maximal velocity and the distance from the start in which they achieved maximal velocity. The testing was conducted as part of regular training sessions with elite rugby players.

3.3.2 Subjects

A group of players (n=11) underwent an assessment of their sprinting ability. The players (age = 23.5 ± 2.9 y, height = 1.86 ± 0.08 m, mass = 100 ± 9 kg) who participated in the study were a mix of 5 forwards and 6 backs that had played senior international rugby. The national team that all of the players play for is typically ranked 11^{th}-14^{th} place on the International Rugby Board (IRB) world rankings. Eight out of the 11 participants (non-tight 5 players) also played 7s rugby for the national team of the same country (typically 9^{th}-12^{th} in IRB World 7s Series). All participants consented and gave informed written consent to take part in the study which had Institutional Review Board approval.

3.3.3 Procedures

On two separate occasions, one week apart, the players performed four 50 m sprints on artificial field turf on clear warm days without wind. Each of the sprints was filmed using two Nikon J1 video cameras recording at 400 f/s. Calibration markers were placed 0.5 m to either side of the run at 0 m, 6 m, 12 m, 18 m, 24 m, 30 m, 36 m, 42 m, and 48 m. On the first testing session, the cameras recorded two of the sprints of each athlete in the 0-6 m, 6-12 m, 12-18 m, and 18-24 m sections. During the second testing session the cameras recorded two of the sprints of each athlete for the 24-30 m, 30-36 m, 36-42 m, and 42-48 m sections. The participants undertook a 25 minute warm up that included light running, dynamic stretches and five 50 m sprints that progressively increased in intensity from 60% of maximal volitional effort to 95% of maximal effort. After warm-up, the participants were given a four minute break

before they performed their first 50 m sprint. The participants were given four to five minutes of passive rest between each sprint.

In order to assess the sprinting kinematics of each player, stride rate, stride length, velocity, ground contact time and flight time were calculated with the aid of computer software (Kinovea). A stride was considered to be the time from touchdown from one leg to the last instant before touchdown of the other leg. Stride length was determined by measuring the distance between successive toe-off positions in each stride, with the most anterior part of the foot at toe off was used as a marker for measuring stride length. Ground contact times were calculated by counting the number of frames between touchdown and toe-off (0.0025 s per frame). Flight time was determined by counting the number of frames between toe-off and touchdown. Stride rate was determined by dividing one stride by the time taken to complete it (1/ground contact time + flight time). Velocity was determined by dividing the distance of the stride length by the time taken to complete it (contact time and flight time). Reliability of sprinting kinematics was determined by calculating Technical Error of Measurement (TEM) and Interclass Correlations (ICC) from two different trials. Strong reliability was found for velocity (ICC=0.85-0.95, TEM=0.09-0.21 m/s), stride length (ICC=0.75-0.95, TEM=0.02-0.04 m), stride rate (ICC=0.73-0.89, TEM=0.06-0.10 s/s), stride length (ICC=0.74-0.94, TEM=0.02-0.04 m), ground contact time (ICC=0.72-0.98, TEM=0.002-0.004s) and flight time (ICC=0.71-0.77 s, TEM=0.003-0.005 s). Inter-rater reliability of the kinematic analyses was determined by calculating TEM and ICC of the same videos assessed by two different individuals who were experienced analyzing sprinting kinematics. Strong inter-rater reliability for these kinematic

assessment methods were found for stride length (ICC=0.99, TEM=0.017 m), ground contact time (ICC=0.95, TEM=0.005 s), and flight time (ICC=0.84, TEM=0.003 s).

3.3.4 Statistical Analysis

The average of the first three strides was taken for the 0 m to 6 m segment and the average of two strides were recorded during each six meter segment between 6m and 48m. Of the two trials recorded for each segment, the one that had the highest velocity was kept for analysis. In order to characterize changes in the sprinting kinematics over the 50m distance, a one way ANOVA was used to determine differences in means between the different sections. If a significant result was found (P<0.05), a Tukey's post-hoc analysis was used to determine differences between the different sections.

3.4 RESULTS

Mean results for each of the section of the 50 m sprints are displayed in Table 1 and Figure 2. Velocity peaked at either the 33 m or 39 m mark for each athlete (Table 2) with the group average of 33 m. There were significant differences in velocity between the 33 m mark and velocities at 3 m, 9 m and 15 m (P<0.05 - P<0.0001), yet differences in velocity at the 21 m mark and any of the distance measured after were non-significant (P=0.886 – P=0.99). No significant differences were found for stride rate between any of the different distances measured. Ground contact time at the 3 m mark was significantly longer than at every other distance measured (P<0.0001), with ground contact time at 9 m significantly different from every other section except for at the 15 m mark. Flight time at 3 m and 9 m was shorter than every other distance

($P<0.0001$). Stride length was significantly shorter at the 3 m mark ($P<0.0001$) than every other section. Stride length at 9 m was also significantly different than every other section ($P<0.001$) with the exception of 15 m ($P=0.242$).

Table 1: Mean and standard deviation of kinematic parameters of elite rugby players (n=11) measured at 3m, 9m, 15m, 21m, 27m, 33m, 39m and 45m of 50m sprints. Significant differences between the different sections of the sprint, calculated by an ANOVA and Tukey's post hoc analysis, are listed below the means of each section. ***P<0.05, **P<0.001, *P<0.0001

	3m x̄ *S*	9m x̄ *s*	15m x̄ *s*	21m x̄ *s*	27m x̄ *s*	33m x̄ *s*	39m x̄ *s*	45m x̄ *s*
Velocity (m/s)	5.22 ±0.3 9m*, 15m*, 21m*, 27m*, 33m*, 39m*, 45m*	7.55 ±0.5 3m*, 15m***, 21m*, 27m*, 33m*, 39m*, 45m*	8.25 ±0.5 3m*, 9m***, 33m***, 39m***	8.69 ±0.55 3m*, 9m*	8.70 ±0.51 3m*, 9m*	8.98 ±0.52 3m*, 9m*, 15m***	8.97 ±0.61 3m*, 9m*, 15m***	8.82 ±0.59 3m*, 9m*,
Stride Length (m)	1.22 ±0.12 9m*, 15m*, 21m*, 27m*, 33m*, 39m*, 45m*	1.71 ±0.14 3m*, 21m**, 27m**, 33m*, 39m*, 45m*	1.87 ±0.13 3m*, 45m***	1.98 ±0.13 3m*, 9m**	1.97 ±0.15 3m*, 9m**	2.06 ±0.16 3m*, 9m*	2.05 ±0.17 3m*, 9m*	2.08 ±0.18 3m*, 9m*, 15m***
Stride Rate (Strides/s)	4.24 ±0.43	4.43 ±0.33	4.43 ±0.28	4.39 ± 0.22	4.40 ±0.31	4.37 ±0.28	4.39 ±0.26	4.27 ±0.22
Ground Contact Time (s)	0.174 ±0.02 9m*, 15m*, 21m*, 27m*, 33m*, 39m*, 45m*	0.135 0.01 3m*, 21m***, 27m**, 33m**, 39m*, 45m**	0.122 ±0.01 3m*	0.117 ±0.01 3m*, 9m***	0.112 ±0.01 3m*, 9m**	0.111 ±0.01 3m*, 9m**	0.113 ±0.01 3m*, 9m**	0.115 ±0.01 3m*, 9m**
Flight Time (s)	0.061 ±0.01 9m*, 15m*, 21m*, 27m*, 33m*, 39m*, 45m*	0.093 ±0.01 3m*, 15m*, 21m*, 27m*, 33m*, 39m*, 45m*	0.106 ±0.01 3m*, 9m*	0.111 ±0.01 3m*, 9m*	0.115 ±0.01 3m*, 9m*	0.118 ±0.01 3m*, 9m*	0.115 ±0.01 3m*, 9m*	0.121 ±0.01 3m*, 9m*

Table 2: Individual maximal velocity characteristics of international rugby players

Position	Maximal Velocity (m/s)	Distance Maximal Velocity Achieved (m)	Stride Length (m)	Stride Rate (strides/s)	Ground Contact Time (s)	Flight Time (s)
Winger	10.0	39m	2.16	4.62	0.104	0.111
Scrum half	9.2	33m	1.91	4.79	0.097	0.111
Openside Flanker	9.2	33m	1.99	4.49	0.107	0.111
Blindside Flanker	8.6	33m	1.83	4.60	0.108	0.109
Flyhalf	9.1	33m	2.00	4.53	0.106	0.114
Openside Flanker	9.3	33m	2.22	4.28	0.113	0.120
Lock	8.4	33m	2.17	3.86	0.127	0.132
Inside Center	9.2	33m	2.20	4.04	0.105	0.134
Winger	9.8	33m	2.23	4.38	0.107	0.121
Hooker	8.0	33m	1.76	4.55	0.126	0.093
Number 8	9.2	39m	2.28	4.00	0.123	0.127

Figure 2: Sample pictures of a player at touchdown at different points of a 50m sprints. From left to right the pictures are at 3 m, 9 m, 15 m, 21 m, 27 m, 33 m, 39 m and 45 m.

Table 3: Sample sprint specific, strength, power and plyometric exercises that are likely to be most beneficial for improving performance during different phases of a sprint.

Exercises	Initial Acceleration (0-6 m)	Mid-Acceleration (6-12 m)	Transition to Maximal Velocity (12-18 m)	Maximal Velocity (18 m +)
Sprint Specific	Sled Sprints Uphill Sprints	Sled Sprints Uphill Sprints	Maximal Velocity Sprints Weighted Vest Sprints	Towed Sprinting Downhill Sprinting Weighted Vest Sprints
Strength and Power	Back Squats Front Squat Split Squat Power Clean Power or Split Snatch Jump Squats Medball Throws	Power Clean Power or Split Snatch Jump Squats Scissor Jumps Glute Ham Raise	Skips with a barbell Power Clean Power or Split Snatch Jump Squats Scissor Jumps Glute Ham Raise Split Jerk	Skips with a barbell Power Clean Power or Split Snatch Jump Squats Scissor Jumps Glute Ham Raises Split Jerk
Plyometric	Broad Jump Multiple Broad Jumps Borzov Jumps	Multiple Broad Jumps Bounding	Drop Jumps (>40cm) Repeated Hurdle Jumps Maximal Stepping Maximal Hopping Bounding Straight Leg Bounding	Drop Jumps (>80cm) Repeated Hurdle Jumps Maximal Stepping Maximal Hopping Bounding Straight Leg Bounding

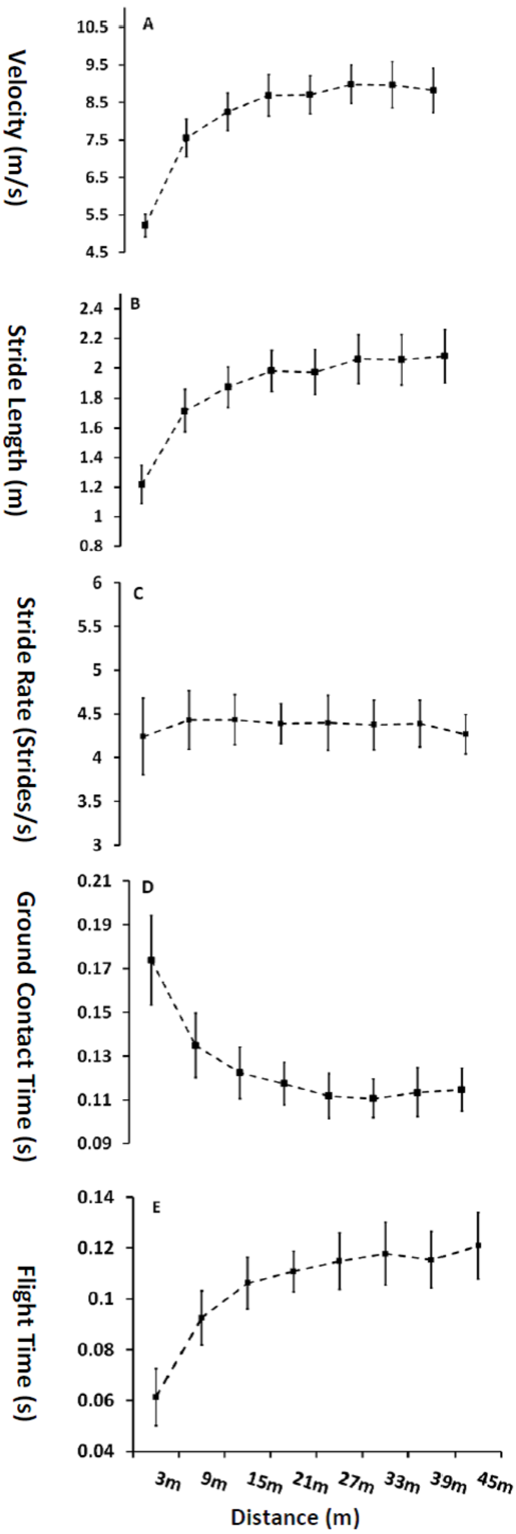

Figure 3: Kinematic parameters of elite rugby players (n=11) measured at 3 m, 9 m, 15 m, 21 m, 27 m, 33 m, 39 m and 45 m of 50 m sprints. The mean and standard deviation are displayed below for velocity (A), stride length (B), stride rate (C), ground contact time (D) and flight time (E).

3.5 DISCUSSION

A key finding of this study was that all players hit their maximal velocity between 30 m and 40 m. This is similar to findings by Higham and colleagues (Higham et al., 2013) who found that international caliber 7s rugby players hit their top velocity during a 40 m sprint in the last 10 m. The players achieved maximal velocity by maintaining stride rate (~4.4 m/s) and increasing stride length (1.22 m to 2.06 m). Flight time and ground contact time were inversely proportional as the players decreased ground contact time (0.174 s to 0.111 s) and increased flight time (0.061 s to 0.118 s) as they increased velocity from the initial velocity at 3 m (5.22 m/s) up to maximal velocity (8.98 m/s) at 33 m.

An interesting aspect of the results was the change in kinematics that the players made transitioning from a standing start up to maximal velocity. The first 3 m were significantly different than every other section of the 50 m sprints with longer contact times, shorter stride lengths and shorter flight times. The kinematics measured at 9 m displayed shorter contact times, longer flight times and longer stride lengths than at 3 m. They were, however, all significantly different with those kinematics at maximal velocity.   This supports the idea of considering acceleration as more than one separate zone.   The kinematics measured at 15 m would suggest that it was the transition phase into the maximal velocity phase as it was not significantly different than 9 m or 21 m for key kinematic variables other than velocity. Despite that all of the athletes hit their maximal velocity at either 33 m or 39 m (Table 2), it could be asserted that the players were in the maximal velocity phase at 21 m. On average, the players were at 96% of the maximal velocity at 21 m and only small and non-significant

changes in ground contact time and stride length took place thereafter. It was not surprising though that lowest ground contact times coincided with reaching maximal velocity. This supports the idea that when an athlete cannot further decrease their ground contact time and still be able to develop the necessary impulse to further increase velocity, they will have hit their maximal velocity (Weyand & Davis, 2005).

The changes in kinematics of the present study would also lend credence to the notion that there are different sprint qualities that need to be considered. Approximately the first 6 m of a sprint from a standing start could be considered *Initial Acceleration,* 6 m to 12m could be considered *Mid-Acceleration*, 12 m to 18 m could be the *Transition to Maximal Velocity* and after 18m could be considered the *Maximal Velocity* phase for this population of athletes. Data from elite sprinters would suggest that they accelerate up to maximal velocities over longer distances and likely transition through these phases at further distances than the rugby players in the current study. It is possible that with training, players could change their acceleration profiles and achieve their maximal velocity later.

The different phases would suggest that different training methods and drills are needed for each phase based on their unique sprinting kinematics. For instance, improving performance in *Initial Acceleration* would likely be achieved by optimizing impulse through an increase in forward lean (Kugler & Janshen, 2010) and by developing force faster to decrease ground contact time (Lockie, Murphy, Knight, & de Jonge, 2011; Murphy et al., 2003). *Mid-Acceleration* is likely improved through a decrease in ground contact time (Lockie et al., 2011; Lockie, Murphy, Schultz, Jeffriess, & Callaghan, 2013) or by increasing horizontal propulsive impulse (Kawamori et al.,

2013). Increasing *Maximal Velocity* is likely done by improving the ability to develop the necessary impulse in a shorter period of time (Bushnell & Hunter, 2007; Weyand et al., 2010). Ground contact time should be a key consideration when considering strength or plyometric exercises used to improve different sprint qualities. Exercises that are effective for improving *Initial Acceleration* might not be effective for improving *Maximal Velocity* based on the time to develop force in the exercise. This may the case because of the differences in ground contact time (0.17 s vs 0.11 s) between the different phases.

An individualized approach to training programs can be used for training programs by using high speed video cameras and video analysis software. Exercises can then be selected based on individual weaknesses during the different phases (Table 3). For example, if video analysis determined stride length of a player during Initial Acceleration or Mid-Acceleration is a weakness, drills and exercises focusing on concentric strength and power of the hip and knee extensors are likely most important (Lockie et al., 2011). This can be accomplished through a combination of exercises such as sled resisted sprints, squats (Lockie, Murphy, Schultz, Knight, & Janse de Jonge, 2012) and variations of the Olympic lifts (Tricoli et al., 2005). On the other hand, if shortening ground contact time during Maximal Velocity is determined to be an important training goal, exercises focusing on increasing the eccentric rate of force development and concentric power of the hip and knee extensors would likely be beneficial (Mann, 2011) . Improving these qualities could lead to a decrease in ground contact time. This could be accomplished by using a program emphasising downhill or towed sprints (Mero & Komi, 1986; Paradisis & Cooke, 2006), drop jumps (Wilson,

Murphy, & Giorgi, 1996) and other plyometric exercises such as maximal speed bounding, hopping and stepping drills (Mero & Komi, 1994). For instance, the two wingers in the study had maximal velocities of 9.8 m/s and 10 m/s. If the slower winger wanted to increase his maximal velocity to equal the faster winger, he could do so by decreasing his average maximal velocity ground contact time by 0.07 s. This goal could be accomplished by designing a training program built around some of the exercises from Table 3 that are specific to the Maximal Velocity phase of sprinting.

3.6 PRACTICAL APPLICATIONS

Given the unique nature of each phase of a sprint, coaches working with athletes should test sprints by examining different sections of a sprint rather than just recording the time taken to complete a relatively long pre-set distance. This can be accomplished by assessing 10 m splits rather than just recording the time taken to complete a single 40 m or 50 m distance. Additionally, in recent years, high speed video cameras and software to analyze video have become considerably less cost prohibitive, and as such an in depth assessment of sprinting kinematics can realistically be performed in many settings. High speed video cameras can be used to record sprinting kinematics if metrics such as stride length, frequency, and ground contact time are being monitored in response to specific training interventions. Assessing sprint qualities in this manner will allow for training programs to be designed to address specific weak areas in the overall sprint performance.

A key finding of this study is that elite rugby players achieve their top speed between 30 and 40 m and do so by decreasing ground contact time and increasing stride length as they accelerate from a standing start. The maximal velocity they attain also

corresponds with the lowest ground contact time. Sprinting can be divided into several sections based on kinematic differences between them. These sections are *Initial Acceleration*, *Mid-Acceleration*, *Transition to Maximal Velocity* and *Maximal Velocity*. In a population of elite rugby players, *Initial Acceleration* is approximately the first 6m, *Mid-Acceleration* is between 6 m and 12 m, *Transition to Maximal Velocity* is between 12 m and 18 m whilst the *Maximal Velocity* phase takes place beyond 18 m.

Chapter 4

The Effect of Ball Carrying on the Sprinting Speed of International Rugby Union Players

Barr, Matthew J., Sheppard, Jeremy M., Gabbett, Tim J., and Newton, Robert U., The effect of ball carrying in the sprinting speed of international rugby union players, *International Journal of Sport Science and Coaching,* In Press

4.1 Abstract

Speed is considered to be a highly valuable ability in rugby union. One unique aspect of rugby is that players need to be effective at sprinting while carrying a rugby ball. Previous research reported that amateur club players were slower while sprinting with the ball, than without. The purpose of the current research was to examine how sprinting while carrying a ball affected the sprinting speed of international rugby players. Twenty-six international players performed 6 x 40 m sprints under three conditions: Ball One Hand (B1H), Ball Two Hands (B2H) and No Ball (NB). Timing gates were placed at the 0 m, 10 m, 30 m and the 40 m mark of the sprint. The 0-10m was used to examine initial acceleration; 30-40 m was used to examine maximal velocity and the 10-30 m section to analyze the acceleration up to maximal velocity. Comparisons were also made between backs and forwards. Backs were found to be faster than forwards at each of the splits for the NB, B1H and B2H conditions (0.04 – 0.08 s, $P<0.0001$ – $P=0.015$, $d=0.88$ – 1.35). The results of the study showed only trivial and small differences (1-2%) between the B1H and B2H conditions with the NB condition. The decrements in speed from the B2H conditions were much less for the international players when compared with previously reported data from amateur club players. Coaches working with rugby players should regularly incorporate sessions focused on speed development, as well as including B1H and B2H as part of a speed testing battery.

KEY WORDS: acceleration, speed testing, maximal sprinting velocity, rugby skills

4.2 Introduction

Speed is considered to be a highly valuable ability in rugby union and a key component of a team's success (Duthie, Pyne, Marsh, et al., 2006). There are several aspects of sprinting that are unique and specific to rugby players. One key difference in sprinting performances between a track and field sprinter and a rugby union player is the requirement of rugby players to run fast, while also carrying a rugby ball. Ball carrying is an essential skill for rugby players because tackle breaks are a key element of game play that discriminates winning and losing teams (Ortega et al., 2009; Wheeler, Askew, & Sayers, 2010). An important aspect of producing tackle breaks in rugby is the speed in which ball carriers carry the ball towards the defensive line (Sayers & Washington-King, 2003; Wheeler et al., 2010); players must be fast while carrying a ball. Being proficient at carrying the ball in one hand is important because it allows a player to adopt fending strategies during contact which greatly contribute to the potential of a tackle break (Wheeler & Sayers, 2009). Another important aspect of tackle breaks is the fact that the vast majority occur in a one on one situation, so creating situations where only a single defender attempts to tackle a ball carrier is ideal. Carrying the ball in two hands likely contributes to creating a one on one tackling situation as defenders need to stay covering other players because the ball carrier could potentially pass to them. If a player puts the ball in one hand it is highly unlikely that he will pass the ball so other defenders could then commit to tackling the ball carrier and create a mismatch that favours the defensive team. For these reasons, elite rugby players need to be proficient at carrying the ball in both one and two hands.

Previous research has shown that amateur rugby players are slower while carrying a rugby ball when compared to sprinting without a ball (Grant et al., 2003; Walsh et al., 2007) and this difference was more pronounced in university players who had just recently taken up the sport (Walsh et al., 2007). Sprinting with a rugby ball is a unique skill because the normal movement that the arms make while sprinting to counterbalance the rotation of the hips is most likely affected by the ball (Grant et al., 2003; Walsh et al., 2007). It may be a trainable skill and elite rugby players, who presumably are accustomed to this skill, might show minimal performance decrements while sprinting with a ball. If this was the case, then performing sprint training while carrying a ball may need to be a key focus of training in sub-elite players. To date, no study has examined the influence of carrying a rugby ball on sprinting speed in elite rugby players. The purpose of the current study was to understand how carrying a rugby ball might influence the sprinting speed of elite rugby players. It was hypothesized that international level rugby players would show lower decrements in sprinting performance with a ball when compared with previous research examining lower level amateur players.

4.3 Methods

4.3.1 Subjects

Twenty-six international rugby union players (14 forwards, 12 backs) took part in the study (age = 26.2 ± 3.2 years, body mass = 101.6 ± 11.9 kg, height = 1.84 ± 0.1 m). All participants were members of the same national team (typically 11^{th} - 15^{th} place in the International Rugby Board world rankings) and had played in International Rugby Board (IRB) test matches against other national teams. While not involved in national

team duty, all of the players either played for European professional clubs or were part of a national team academy with a daily training schedule similar to that of a professional club. All of the participants consented to have their testing results used and the study had Institutional Review Board approval.

4.3.2 Testing

The players performed 6 x 40 m sprints total, with two repetitions each of the three different conditions: sprinting with a ball in one hand (B1H), sprinting with a ball in two hands (B2H) and sprinting without a ball (NB). Each of the sprints with the ball was performed with an IRB approved ("IRBlaws.com," n.d.) Gilbert match ball. The sprint testing was performed on a firm dry pitch with short cut grass on a warm clear day with no wind. The sprints were tested using a Brower TC timing system (Brower, Utah) with gates set on 1 m tripods at 0 m, 10 m, 30 m, and 40 m. The participants were instructed to begin with their front foot beside a marker that was placed 0.75 m in front of the first gate. The gates were set at this height because gates set higher than hip height have lower typical error (Cronin & Templeton, 2008).

The order of the trials was randomized for each subject to balance the possible effects of fatigue. Each subject completed at least one trial of each condition before their second round where they completed trials in the same order. A rest time of four to five minutes was given between each trial. The 0-10 m, 10-30 m and 30-40 m splits from the trial that had the fastest 40 m time, under each condition, was kept for analysis. The 0-10 m split is representative of acceleration ability, the 10-30 m split is a transition to maximal velocity, and maximal velocity is achieved between 30 m and 40 m in international rugby players (Barr, Sheppard, & Newton, 2013). Velocities were

also calculated for each split by dividing the distance of the split by the time taken to complete it.

4.3.3 Statistical Analysis

The trial with the fastest 40 m time under each of the three different ball carrying conditions was kept and compared using a two way (Position x Ball Carrying Condition) ANOVA. The level of significance was set at $p \leq 0.05$. If a significant F value was found then a Tukey's post hoc test was used to determine the source of these differences. In order to characterize the differences between groups, Cohen's *d* effect sizes were calculated with the following classification system used to determine the magnitude of effect (11). Effect sizes (Cohen's *d)* of <0.2, ≥0.2 to <0.6, ≥0.6 to <1.2, ≥1.2 to <2.0, and >2.0 were considered trivial, small, moderate, large, and very large, respectively. The Typical Error of Measurement (TEM) and Intraclass Correlations (ICC) were calculated to determine reliability. All statistical analyses were conducted with XLSTAT (New York, USA) software.

4.4 Results

The reliability of the different splits was found to be high with low TEMs (0.02-0.04 s) and high ICCs for the NB (0.87), B1H (0.85) and B2H (0.77) conditions of the 0-10 m split, the NB (0.77), B1H (0.79) and B2H (0.78) conditions of the 10-30 m split and the NB (0.86), B1H (0.90) and B2H (0.89) conditions of 30-40 m split. No differences were found between the NB carrying condition with the B1H condition over the 0-10 m split (P=0.95, *d*=0.08), 10-30 m split (P=0.69, *d*=0.25) and 30-40 m split (P=0.99, *d*=0.01). Trivial to small differences were found between the B2H Condition for the 0-10m

(P=0.93, *d*=0.11), 10-30 m (p=0.85, *d*=0.17), and 30-40 m splits (P=0.65, *d*=0.25) with the NB conditions. While there were no significant differences between the 3 conditions, 38% of the players in the maximal velocity phase had decrements in speed greater than the TEM but no players had speed decrements greater than the TEM in the acceleration phase. The forwards were found to be slower than the backs for the 0-10 m phase under the NB (P=0.015, *d*=0.93), B1H (P<0.006, *d*=1.04), and B2H (P=0.021, *d*=0.88) conditions. They were also found to be slower for NB (P<0.0001, *d*=0.88), B1H (P=0.022, *d*=0.88), B2H (P=0.001, *d*=1.23) for the 10-30 m split as well as the NB (P<0.0001, *d*=1.29), B1H (P<0.0001, *d*=1.35), and B2H (P=0.002, *d*=1.15) conditions of the 30-40 m split.

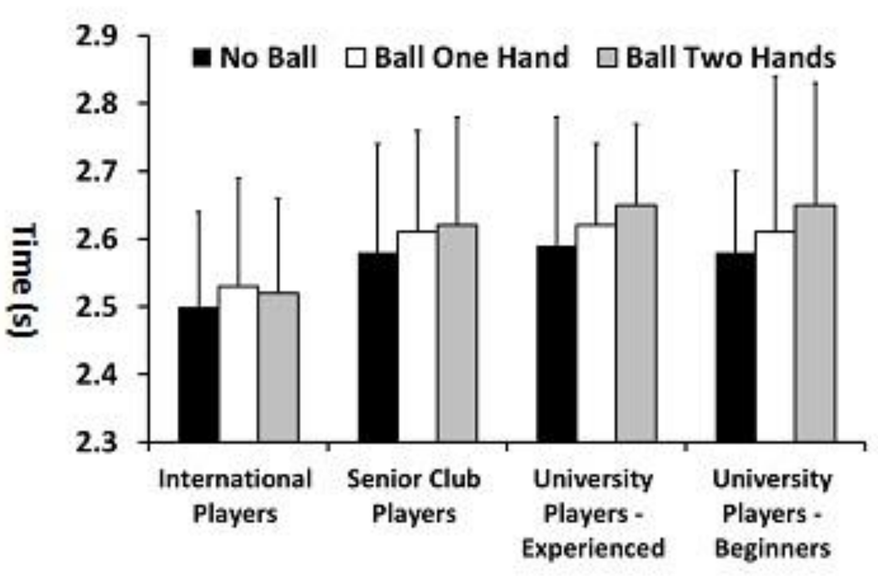

Figure 4: Comparison between the current study (n=26) and previous studies (6, 7) examining club (n=48), inexperienced university (n=12) and experienced university (n=22) players on the time taken to cover between the 10 m mark and the 30 m mark of a sprint. The No Ball conditions are in black, the Ball in One Hand conditions is in white, and the Ball n Two Hands conditions is in grey.

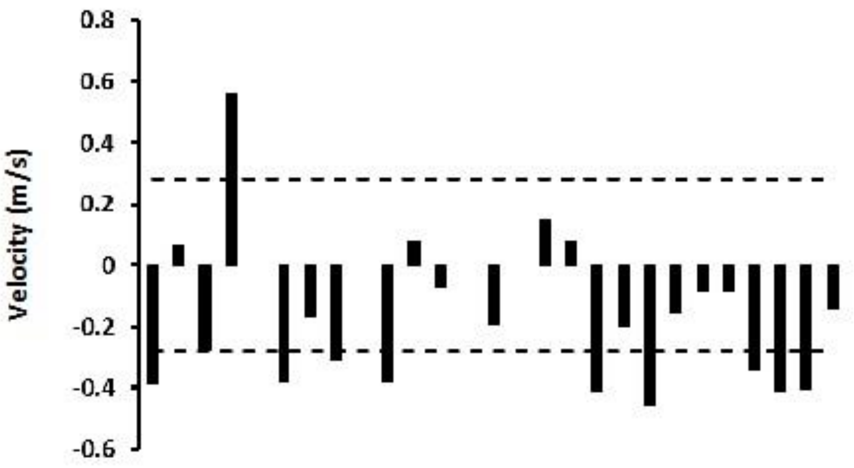

Figure 5: Individual velocity differences between the No Ball condition and the Ball Two Hands Condition for maximal sprinting velocity (30-40 m split). Bars represent individual scores with positive scores meaning the athlete was faster with the ball in two hands and negative scores indicating they were slower in the Ball Two Hands condition compared to the No Ball condition. Dashed bars indicate the Typical Error of Measurement for the No Ball condition.

Figure 6: Individual differences between the No Ball condition and the Ball Two Hands Condition for acceleration (0-10 m split). Bars represent individual scores with positive scores meaning the athlete was faster with the ball in two hands and negative scores indicating they were slower in the Ball Two Hands condition compared to the No Ball condition. Dashed bars indicate the Typical Error of Measurement for the No Ball condition.

Table 4: Comparison between sprinting speeds in each of the ball carrying conditions for the group. Differences between the No Ball condition and One Hand Carry condition and No Ball condition and Two Hand Carry condition are listed below the mean scores of each condition. P values effect size differences are listed in parentheses.

	0-10m (s)		**10-30m (s)**		**30-40m (s)**	
	Mean	SD	Mean	SD	Mean	SD
No Ball	1.82	0.08	2.50	0.14	1.18	0.08
Ball One Hand	1.81	0.09	2.53	0.16	1.18	0.09
difference from No Ball condition	*(P=0.95, d=0.08)*		*(P=0.69, d=0.21)*		*(P=0.99, d=0.01)*	
Ball Two Hands	1.81	0.09	2.52	0.14	1.2	0.09
difference from No Ball condition	*(P=0.93, d=0.10)*		*(P=0.85, d=0.10)*		*(P=0.65, d=0.25)*	

Table 5: Comparison between forwards and back for sprinting speeds in each of the ball carrying conditions. Differences between the Forwards and Backs for each of the conditions are listed below with the P value from the Tukey's post-hoc analysis and the effect sizes listed on the bottom.

		0-10 m (s)			**10-30 m (s)**			**30-40 m (s)**		
		No Ball	Ball One Hand	Ball Two Hands	No Ball	Ball One Hand	Ball Two Hands	No Ball	Ball One Hand	Ball Two Hands
Forwards	Mean	1.85	1.86	1.85	2.58	2.60	2.60	1.23	1.24	1.25
	SD	0.08	0.09	0.09	0.12	0.13	0.14	0.09	0.08	0.08
Backs	Mean	1.78	1.76	1.77	2.40	2.45	2.42	1.12	1.12	1.15
	SD	0.06	0.06	0.06	0.08	0.17	0.08	0.05	0.04	0.05
Difference between forwards and backs		0.07 s P=0.015 *d*=0.93	0.05 s P=0.006 *d*=1.04	0.04 s P=0.021 *d*=0.88	0.08 s P<0.0001 *d*=1.33	0.07 s P=0.022 *d*=0.88	0.08 s P=0.001 *d*=1.23	0.05 s P<0.0001 *d*=1.29	0.06 s P<0.0001 *d*=1.35	0.05 s P=0.002 *d*=1.15

4.5 Discussion

As hypothesised, international rugby players displayed superior sprinting speed (Table 4, Figure 4) when compared with studies that have previously examined this topic with amateur club players (Grant et al., 2003; Walsh et al., 2007). A key finding of this study is the trivial differences between the B2H condition and NB condition in the 10 – 30 m split (Figure 4, Table 4). The small difference in the 10-30 m split between the NB condition and the B1H (0.03 s, P=0.69) condition was similar to the differences (0.03 s) previously reported in male club players (Grant et al., 2003; Walsh et al., 2007). The trivial difference (0.02 s, P=0.93, d=0.11) in this study between the B2H and NB conditions was, on the other hand, less than previously reported in university club players who had recently taken up the game (0.07 s), experienced university age club players (0.06 s), and senior men's club players (0.04 s) (Grant et al., 2003; Walsh et al., 2007). The differences between the current study and the other studies that have examined ball carrying speed would suggest that carrying a rugby ball in two hands is a trainable skill, or at very least the sprinting speed of international rugby players is more resistant to decrements when carrying a ball in one and two hands. In the current study, forwards were found to be slower (Table 5) than backs and this is consistent with other research (Duthie, Pyne, Marsh, et al., 2006). It might be expected that because backs spend more time performing ball carrying drills that they might be superior at sprinting while carrying a ball but both groups were similarly unaffected by sprinting with a rugby ball. Through frequent ball carrying and passing drills in training sessions, elite players likely develop the ability to compensate for the effect that carrying a ball has on their arms while sprinting.

The arms are considered to be important for balancing the angular momentum produced by the legs (Hamner, Seth, & Lelp, 2010; Mann, 1981) so an athlete carrying an object in their hands could potentially affect sprinting speed by disrupting arm movement. The mass of the ball (0.45 kg) though would not seem to affect sprinting speed given that previous research showed that sprinting with a 0.44 kg weight in either hand did not affect sprinting velocity (Ropret, Kukolj, Ugarkovic, Matavulj, & Jaric, 1998). The trivial differences between the NB and B1H condition for the 0-10 m split (P=0.9, *d*=0.08) and the 30-40 m split (P=0.99, *d*=0.01) suggest that elite rugby players can adequately use their arms for balance while holding a ball and sprinting. Peak velocity occurs between 30-40 m in elite rugby players (Barr et al., 2013) so it would be expected if the players were to struggle while carrying a ball in two hands, it would likely happen over this distance. There was a small and non-significant difference between the NB condition and B2H condition (P=0.65, *d*=0.25) but individual results showed that there were 10 individuals whose B2H velocities were slower and outside the TEM of the No Ball conditions (Figure 5). This would suggest that some players were unable to effectively use their arms for balance while holding a ball in two hands. This is relevant because most elite players typically hit maximal velocity during games (Duthie, Pyne, Marsh, et al., 2006).

While sprinting, athletes typically move their arms forward and backward in the sagittal plane to counterbalance the rotation of the hips generated by the angular momentum of their legs (Hamner et al., 2010; Mann, 1981). This means that the arms used to counterbalance this rotation, is undoubtedly affected by sprinting with the ball in two hands. Another sport that is required to compensate for the effect of a reduced

role of the arms while sprinting is pole vault as pole vaulters face a similar problem in trying to sprint without the normal use of their arms. Sprinting while carrying a pole negatively affects sprinting velocity by decreasing the maximal hip flexion during the swing phase (Frere, Chollet, & Tourny-Chollet, 2009). The lower hip and knee flexion causes a higher braking phase, which both results in a lower stride length and a lower sprinting velocity (Frere et al., 2009). The mass and shape of a pole likely make it impossible to balance the torques produced by the legs but a rugby ball is much lighter and smaller so there may be a specific technique for sprinting with the ball in two hands that allows players to counter-balance the rotation of the hips (Mann, 1981) and minimize the loss of speed from sprinting with a ball. It is common to see elite players shift the ball side to side while carrying the ball. This likely helps balance the rotation of the hips from the angular momentum produced by the legs so that it does not affect the hip and knee flexion during the swing phase and reduce stride length (Frere et al., 2009).

Mastering the ability to carry the ball in two hands is an important skill for rugby players; not only do players require the ability to maximize their sprinting speed while carrying a ball, but they also create uncertainty with defenders if they are able to carry the ball in two hands while moving at speed. For instance, if a player struggles while carrying a ball they may be more likely to make a passing error after catching a ball while sprinting at a near maximal velocity. Professional players frequently sprint at or near their maximal velocity in games (Austin et al., 2011b; Duthie, Pyne, Marsh, et al., 2006). Some positions, such as fly-half and scrum-half may touch the ball over 40 and 70 times each per game, respectively (Quarrie, Hopkins, Anthony, & Gill, 2013) so ball

carrying ability is a highly important skill for those positions. Even positions such as prop, who handle the ball the least of any position in international rugby, may touch the ball as many as 10 times per game (Quarrie et al., 2013). Further research is required to determine if players who struggle sprinting with the ball in two hands make more passing errors while sprinting with the ball in two hands.

Sprint training sessions with rugby players should regularly incorporate ball carrying drills so that players can develop the ability to sprint with a ball at maximal velocities. Given the importance of ball carrying ability, we also suggest that coaches working with rugby teams include sprinting with a ball in their testing batteries. This would allow for the identification of players whose performance is limited while sprinting with a ball (similar to the individual response shown in Figures 5 and 6). An individualized approach could then be taken so that ball carrying drills can be built into sprint training sessions to develop areas of weakness. Speed training for rugby players could then have a periodized approach where blocks of training can shift back and forth from sprinting without a ball to sprinting with a ball. This would allow players to improve sprinting speed with traditional speed training methods and then ensure that the speed increases are transferred to improvements in ball carrying ability. This periodized approach is particularly relevant for sub-elite player transitioning into professional and international rugby, and for 'second tier' rugby nations developing their elite squads through talent transfer programs (e.g. gridiron football players converting to Olympic rugby sevens and to rugby union World Cup programs).

4.6 Practical Applications

Ball carrying ability should be a key consideration for strength and conditioning coaches evaluating the sprinting ability of rugby players. The findings of the current study would suggest that carrying a rugby ball in two hands does not negatively affect the sprinting speed of elite rugby players to the same extent that has previously been reported in sub-elite players. It is suggested that coaches working with rugby players should consider implementing a testing protocol that utilizes both sprints with and without a rugby ball. If a player has deficiency in ball carrying ability, it is likely that they will benefit from additional ball carrying drills during speed sessions. Long term training plans for players transitioning from sub-elite to elite rugby should focus on teaching players to sprint with a rugby ball in two hands.

Chapter 5

Long-term Training Induced Changes in Sprinting Speed and Sprint Momentum in Elite Rugby Union Players

Barr, Matthew J., Sheppard, Jeremy M., Gabbett, Tim J., and Newton, Robert U., Long-term training induced changes in sprinting speed and sprint momentum in elite rugby union players, *Journal of Strength and Conditioning Research*, 28, 10, 2724-2731, 2014.

5.1 Abstract

Speed and sprint momentum are considered to be important physical qualities for rugby. The purpose of the study was to understand the development of these qualities in senior and junior international rugby players. In Part 1 of the study, a group of senior (n=38) and junior (n=31) players were tested for speed over 40 m. Initial Sprint Velocity (ISV), Maximal Sprint Velocity (MSV), Initial Sprint Momentum (ISM) and Maximal Sprint Momentum (MSM) were calculated using 10 m splits. In Part 2 of the study, a group of junior (n=12) and senior (n=15) players were tracked over a two year period for body mass, ISV, MSV, ISM and MSM. In Part 1, senior backs and forwards were not found to have significantly greater ISV and MSV than junior players but were found to have greater ISM and MSM. Forwards were found to have significantly greater ISM and MSM than backs but significantly lower ISV and MSV than backs. In Part 2, no significant differences were found over the two years between senior and junior players but greater effect sizes for juniors were generally found when compared to seniors for improvements in ISV (d=0.73 vs 0.79), MSV (d=1.09 vs 0.68), ISM (d=0.96 vs 0.54) and MSM (d=1.15 vs 0.50). Sprint momentum is a key discriminator between senior and junior players and large changes can be made by junior players as they transition into senior rugby. Speed appears to peak for players in their early twenties but sprint momentum appears to be more trainable.

KEY WORDS: acceleration, maximal sprinting velocity, long term athlete development.

5.2 Introduction

Speed is commonly considered to be a highly valuable ability in rugby union and a key component of a team's success (Duthie, Pyne, Marsh, et al., 2006). A notable difference between specialist sprinters competing in track and field and rugby players is body mass. When examining historical data of the body types of elite sprinters, it would appear that there exists an optimal body mass for sprinters (Uth, 2005; Watts et al., 2011; Weyand & Davis, 2005) that is not likely optimal for rugby union players (Duthie, Pyne, Marsh, et al., 2006). The mass differences between sprinters and rugby players are likely related to the various collisions in the game that favour heavy body mass (Deutsch, Kearney, & Rehrer, 2007; Quarrie & Wilson, 2000). An indicator of the continued importance of size in rugby union has been the steady increase in body mass of players over the history of the game (Olds, 2001; Sedeaud et al., 2012). The importance of both body mass and sprinting speed in rugby may mean that the combination of the two, sprint momentum, is a more important determinant of success in rugby union. Sprint momentum, calculated by multiplying sprinting velocity with body mass, has previously been found to discriminate between performance levels of elite rugby league players (Baker, Wilson, & Carlyon, 1994) but there is currently a gap in the literature analyzing the importance of sprint momentum in elite rugby union players. Elite rugby union players might choose to play at a body mass that is not optimal for maximizing sprinting speed but optimizes sprint momentum. However, the relationships between sprinting speed, mass and momentum and how they may discriminate between playing levels of elite rugby players are currently unclear.

Previous research that has examined long term changes in strength and power in contact field sport athletes such as rugby union (Appleby et al., 2012), rugby league (Baker & Newton, 2006; Baker, 2013), and American football (Hoffman et al., 2011; Miller et al., 2002; Stodden & Galitski, 2010) players indicated that strength development can continue throughout a playing career. Long term changes in the sprinting speed of American university football players, however, suggest that the development of speed is much more limited when compared with strength (Miller, Umberger, & Caldwell, 2012; Stodden & Galitski, 2010). It may be possible that speed peaks very early as a physical quality in contact field sport athletes but sprint momentum continues to develop for a longer period of time as athletes continue to gain muscle mass (Appleby et al., 2012). There are currently no published studies that have examined whether or not elite rugby union players improve sprint momentum and sprinting speed over several years of training.

The purpose of the study was to understand the development of the sprinting speed and sprint momentum in senior and junior international rugby players. Three different components of sprint momentum and sprinting speed were specifically examined. First, we examined whether speed or momentum could discriminate between senior and junior international rugby union players. Second, we examined whether or not junior rugby union players transitioning into senior rugby develop sprint momentum and speed at greater rates than senior rugby union players. Lastly, we examined the relationship between sprinting speed, sprint momentum and body mass. It was hypothesized that sprint momentum but not speed would discriminate senior and junior union players. It was hypothesized that junior players transitioning

into senior rugby would improve sprint momentum at a greater rate than senior players and would close the sprint momentum gap over two years. It was also hypothesized that body mass would negatively affect sprinting speed but there would be an optimal body mass for maximizing sprint momentum.

5.3 Methods

5.3.1 Experimental Approach to the Problem

In order to understand how sprint momentum and sprinting speed are developed in elite rugby players, the study was divides into two parts. The 1st part consisted of a causal-comparative cross sectional design and 2nd part of the study was a longitudinal quasi-experimental design. The 1st part of the study consisted of determining sprinting velocity, sprint momentum and body mass of 69 junior and senior international rugby players. The 2nd part consisted of tracking the changes in body, sprinting speed and sprint momentum of 28 international rugby union players over a two year period. Two way and repeated measure ANOVAs were used to calculate differences between the different conditions and groups. Correlations were also calculated between mass, sprint momentum and sprinting velocity in Part 1 and the changes in these qualities over two years in Part 2.

5.3.2 Subjects

The participants in the 1st part of the analysis (1.84 ± 0.1 m, 102.8 ± 11.9 kg, 26.2 ± 3.2 years) were 38 senior national team players (21 forwards, 17 backs) from the same national team (typically 11th-15th place in the International Rugby Board world rankings) and 31 under-20 national team players (17 forwards, 14 backs) also

from the same country's national team (1.84 ± 0.1 m, 93.2 ± 12.3 kg, 19.2 ± 0.9 years). The participants in the 2nd part of the analysis were 12 (4 forwards, 8 backs) junior national team players (1.85 ± 0.07 m, 92.2 ± 8.8 kg, 18.9 ± 0.5 years) transitioning into senior rugby and 15 (6 forwards, 9 backs) senior national team players (1.83 ± 0.06 m, 94.6 ± 8.6 kg, 24.1 ± 2.3 years). All of the junior players were playing under-20 national team players at the beginning of the study and had played senior international rugby (IRB test match or A match) by the end of the study. All of the participants involved in the study were training on a full time basis at a national team training academy. Each of the participants were typically involved in approximately 8-12 weeks per year of national team duty, 24 weeks per year of club rugby, 12-16 weeks per year of pre-season training and 4 weeks of rest. Training during national team competition weeks involved 1-2 strength training sessions and 3-4 rugby practices per week. Training during club rugby competition weeks typically involved 2-3 strength training sessions, 1-2 speed training sessions and 2-3 rugby practices per week. Training during pre-season training typically involved 2-3 speed training session, 3-4 strength training sessions and 1-2 rugby practices per week. Given the intense nature of rugby, each player was injured at some point of the study so that their training had to be modified but no players were injured to an extent that long term layoffs (>1 month) occurred. Each participant was following their own individualized training program but typical sprint training sessions were based on the exercises listed in Table 6. Strength training sessions typically consisted of variations of the Olympic lifts, squats, pressing exercises, upper body pulling exercises, plyometrics and other exercises. Each session typically consisted of 4-6 exercises done for 5-8 sets of 1-8 repetitions.

5.3.3 Procedures

Each of the players performed four 40 m sprints on an artificial field using a Brower (Brower Timing Systems, Draper, Utah, USA) system with timing gates placed upon 1 m high tripods at 0 m, 10 m, 30 m and 40 m. The players began each sprint with their front foot beside a cone 0.75 m behind the first gate. The order of the trials was randomized for each subject to balance the possible effects of fatigue. Each subject completed at least one trial of each condition before their second round where they completed trials in the same order. A rest time of four to five minutes was given between each trial. The fastest 0-10 m and 30-40 m splits were kept for analysis. The 0-10 m split is representative of acceleration ability and the 30-40 m split is representative of maximal velocity (Barr et al., 2013). Velocity scores (m/s) were calculated for both of these splits by dividing the 10 m split by the time taken to complete the trial. The 0-10 m split was defined as Initial Sprint Velocity (ISV) and the 30-40 m split as Maximal Sprint Velocity (MSV). The mass of the athlete was multiplied by both velocity scores (kg*m/s) to obtain an Initial Sprint Momentum (ISM) and Maximal Sprint Momentum (MSM) score. Mass, height and sum of 7 skinfolds (bicep, tricep, subscapular, abdominal, supraspinale, front thigh and medial calf) of the athletes were tested using the protocol of the International Society for the Advancement of Kinanthropometry (Stewart, Marfell-Jones, Olds, & de Ridder, 2011) by an ISAK certified tester (Level 2).

Table 6: Typical speed exercises used during training (100-350 m per session total volume).

- Flat sprints (10 - 60 m)
- 3° Uphill Sprints (10 - 20 m)
- Resisted Sled Sprints (5 - 15 m)
- 3° Downhill Sprints (20 - 40 m)
- Change of Direction Drills

5.3.4 Statistical Analysis

Reliability for ISV and MSV were determined to be very reliable with intra-class correlations of r=0.91 and r=0.94. In order to compare mass, momentum, and velocity differences between Under-20 and Senior players in Part 1, a two-way (positional x age group) ANOVA was used. In order to compare changes in mass, momentum, and velocity differences between Under-20 and Senior players in Part 2, a two-way repeated (time x age group) ANOVA was used. The level of significance was set at $p \leq 0.05$. If a significant F value was found then a Tukey's post hoc test was used to determine the source of these differences. Complete data sets of sum of 7 skinfolds were only available for the beginning of the two year period and the end of the two year period so a paired t-test was used to compare them. Pearson's correlations were calculated to characterize the relationship between sprinting velocity, sprint momentum and mass. In order to characterize the differences between groups, Cohen's *d* effect sizes were calculated. The following classification system was used to determine the magnitude (Hopkins, 2011) of Cohen's *d* effect sizes, effect sizes were considered trivial for being <0.2, small for ≥0.2 and <0.6, moderate for ≥0.6 and <1.2, large for ≥1.2 and <2.0, and very large for >2.0. An alpha of $p \leq 0.05$ was set for level of significance for ANOVAs. All statistical analyses were conducted with XLSTAT (Addinsoft, New York, USA) software.

5.4 Results

In Part 1, moderate differences in Initial Sprint Momentum (mean difference: 49 kg*m/s, $p<0.0001$, Cohen's $d=0.81$) and Maximal Sprint Momentum (79 kg*m/s, $p < 0.0001$, $d = 0.95$) were found between Senior and Under-20 players. Trivial differences in Initial Sprint Velocity ($p = 0.426$, $d = 0.17$) and Maximal Sprint Velocity (0.05 m/s, $p = 0.71$, d = 0.09) were found between Senior and Under-20 players. Very large correlations were found between Mass and Maximal Sprint Momentum (r = 0.84) as well Mass and Initial Sprint Momentum (r = 0.92). Large correlations were found between Initial Sprint Velocity (r = -0.52) and Maximal Sprint Velocity (r = -0.68). In Part 2, no significant differences were detected between the Senior and Junior group at any of the time points. The Junior group made large improvements in Maximal Sprint Momentum (mean change: 86 kg*m/s, $p = 0.03$, $d = 1.15$) and Maximal Sprint Velocity (0.5 m/s, $p = 0.02$, $d = 1.09$) and moderate increases in Initial Sprint Momentum (44 kg*m/s, $p = 0.04$, $d = 0.96$) and Initial Sprint Velocity (0.2 m/s, $p = 0.13$, $d = 0.73$,) over the two years. The changes in the Senior group were considerably lower with moderate improvements in Initial Sprint Velocity (0.18 m/s, $p = 0.02$, $d = 0.79$,), Maximal Sprint Velocity (0.27 m/s, $p = 0.24$, $d=0.68$), Initial Sprint Momentum (26 kg*m/s, $p = 0.36$, $d = 0.54$), Maximal Sprint Momentum (37 kg*m/s, $p = 0.42$, $d = 0.50$). Trivial differences ($p = 0.92$, $d = 0.02$) were found for changes in sum of 7 skinfolds between the pre-testing period (65.8 ± 20.0 mm) and end of the two year period (66.3 ± 18.4 mm) in the combined group of Junior and Senior players.

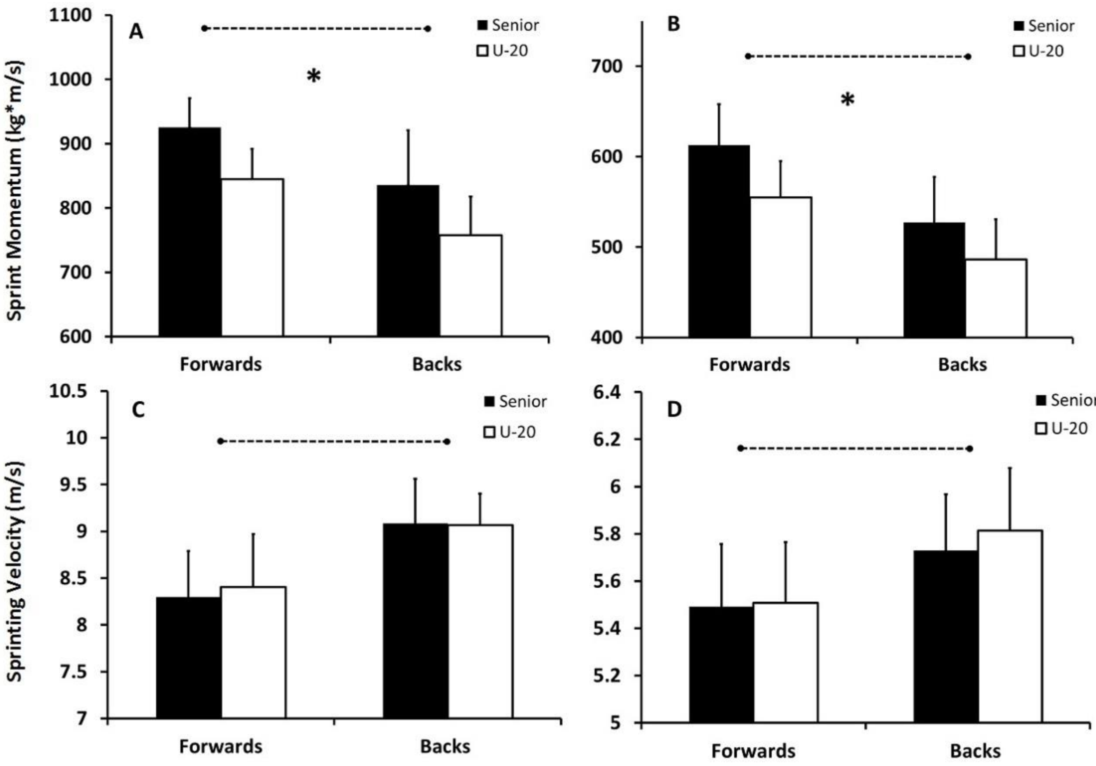

Figure 7: Differences in Maximal Sprint Momentum (A), Initial Sprint Momentum (B), Maximal Sprint Velocity (C) and Initial Sprint (D) between Senior and Under-20 national team rugby Forwards and Backs. Senior group results are in black and under-20 players are in white. Asterisk denotes a significant difference ($p < 0.05$) between Senior and Under-20 players. Dashed line denotes a significant difference ($p < 0.05$) between Forwards and Backs.

Table 7: Differences in Maximal Sprint Momentum, Initial Sprint Momentum, Maximal Sprint Velocity and Initial Sprint Velocity between Senior and Under-20 national team rugby Forwards and Backs. Differences, as calculated by a two way ANOVA and Tukey's post hoc analysis, are listed below with *p* value and effect sizes (Cohen's *d*).

	Initial Sprint Velocity (m/s)		Maximal Sprint Velocity (m/s)		Initial Sprint Momentum (kg*m/s)		Maximal Sprint Momentum (kg*m/s)		Mass (kg)	
	Senior	*Junior*	*Senior*	*Junior*	*Senior*	*Junior*	*Senior*	*Junior*	*Senior*	*Junior*
Forwards	5.49	5.50	8.30	8.40	613	555	925	845	111.7	101.0
SD	0.27	0.26	0.49	0.57	45	40	45	47	6.5	9.6
Backs	5.73	5.81	9.08	9.07	527	486	836	758	91.9	83.7
SD	0.24	0.26	0.48	0.33	50	44	84	60	6.6	7.8
Difference between Under-20 and Senior	*p = 0.426, d = 0.17*		*p = 0.71, d = 0.09*		*p < 0.0001, d = 0.81*		*p < 0.0001, d = 0.95*		*p < 0.0001, d = 0.75*	
Difference between Forwards and Backs	*p < 0.0001, d = 1.04*		*p < 0.0001, d = 1.4*		*p < 0.0001, d = 1.68*		*p < 0.0001, d =1.45*		*p < 0.0001, d = 1.95*	

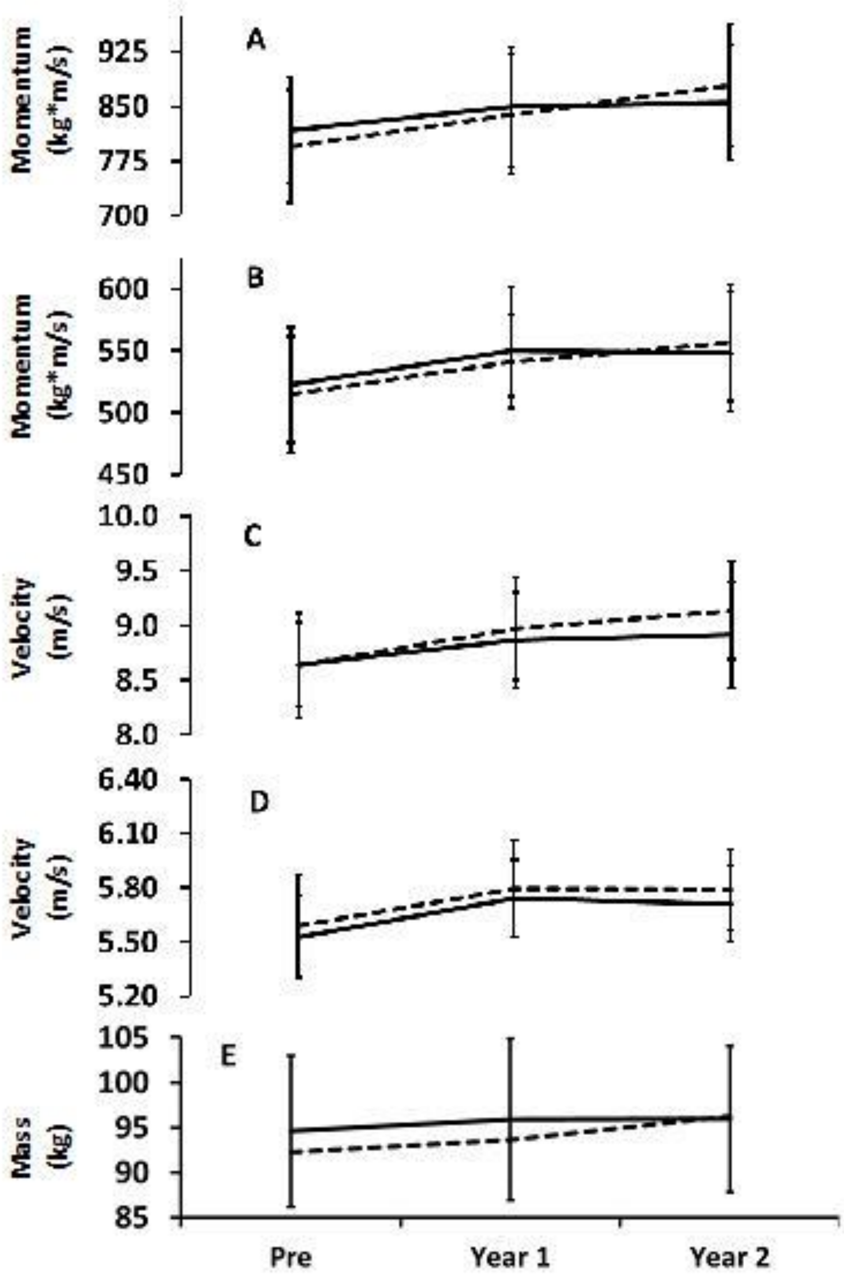

Figure 8 Two year changes in Mass (E), Initial Sprint Velocity (D), Maximal Sprint Velocity (C), Initial Sprint Momentum (B) and Maximal Sprint Momentum (A) of senior international rugby players and junior rugby players transitioning into senior international rugby. Senior players are solid bars and junior players transitioning into senior rugby are denoted with dashed bars. Error bars denote standard deviation.

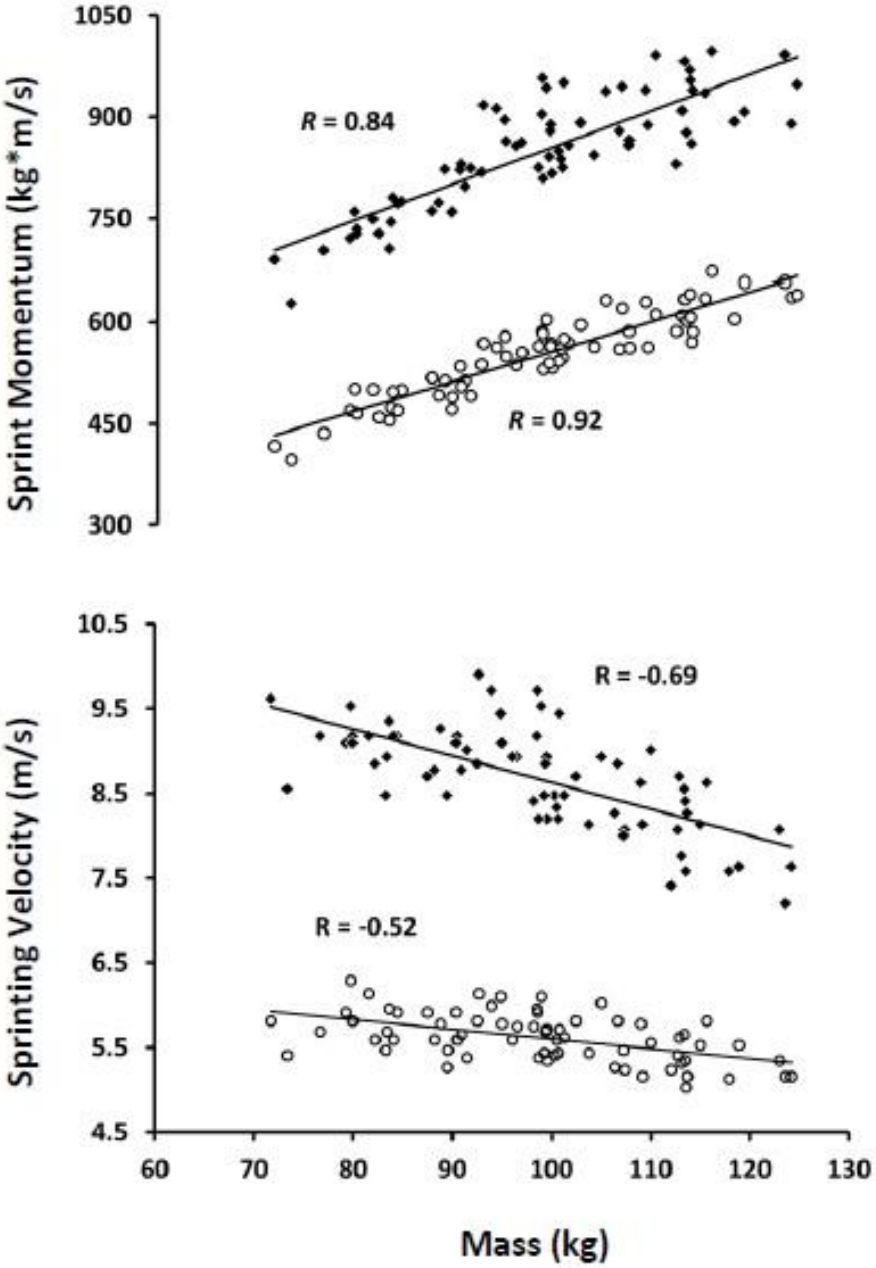

Figure 9: Relationship between body mass and Maximal Sprint Momentum (solid diamonds, top graph), Initial Sprint Momentum (open circles, top graph) and Maximal Sprint Velocity (solid diamonds, bottom graph) and Initial Sprint Velocity (open circles, bottom graph).

Table 8: Two year changes in Mass, Maximal Sprint Momentum, Initial Sprint Momentum, Maximal Sprint Velocity and Initial Sprint Velocity of Senior and Junior national team players transitioning into senior international rugby. Cohen's effect sizes (d) and alpha (P) of differences from the initial testing to the end of the first year and second year are listed below.

	Mass (kg)			**Initial Sprint Velocity (m/s)**			**Maximal Sprint Velocity (m/s)**			**Initial Sprint Momentum (kg*m/s)**			**Maximal Sprint Momentum (kg*m/s)**		
	Pre	*Year 1*	*Year 2*	*Pre*	*Year 1*	*Year 2*	*Pre*	*Year 1*	*Year 2*	*Pre*	*Year 1*	*Year 2*	*Pre*	*Year 1*	*Year 2*
Junior															
x̄	92.2	93.6	96.6	5.59	5.80	5.79	8.64	8.97	9.14	514	541	558	795	839	881
SD	±8.8	±8.3	±9.7	±0.28	±0.26	±0.21	±0.46	±0.45	±0.42	±46	±36	±45	±74	±78	±80
Senior															
x̄	94.6	95.9	95.9	5.53	5.74	5.71	8.65	8.87	8.92	522	550	548	817	849	854
SD	±8.6	±9.2	±8.4	±0.23	±0.21	±0.22	±0.39	±0.45	±0.50	±47	±53	±51	±75	±86	±82
	Pre – Year 1	*Year 1 - Year 2*	*Pre – Year 2*	*Pre – Year 1*	*Year 1- Year 2*	*Pre – Year 2*	*Pre - Year 1*	*Year 1 - Year 2*	*Pre – Year 2*	*Pre- Year 1*	*Year 1 - Year 2*	*Pre – Year 2*	*Pre - Year 1*	*Year 1 - Year 2*	*Pre – Year 2*
Junior															
d =	0.16	0.33	0.50	0.75	0.02	0.73	0.73	0.37	1.09	0.58	0.43	0.96	0.58	0.50	1.15
p =	0.93	0.69	0.46	0.13	0.99	0.13	0.17	0.63	0.02	0.29	0.58	0.04	0.17	0.23	0.01
Senior															
d =	0.15	0.01	0.16	0.92	0.14	0.79	0.55	0.10	0.68	0.59	0.04	0.54	0.43	0.06	0.50
p =	0.89	0.99	0.84	0.004	0.85	0.02	0.39	0.95	0.24	0.30	0.99	0.36	0.28	0.98	0.39

Table 9: Pearson's correlations between momentum, velocity and mass in elite rugby players (n=69).

Initial Sprint Velocity (m/s)				
0.83	Maximal Sprint Velocity (m/s)			
-0.15	-0.40	Initial Sprint Momentum (kg*m/s)		
-0.09	-0.17	0.93	Maximal Sprint Momentum (kg*m/s)	
-0.52	-0.68	0.92	0.84	Mass (kg)

Table 10: Pearson's correlations between changes in momentum, velocity and mass in elite rugby players over two years (n=27).

Initial Sprint Velocity (m/s)				
0.04	Maximal Sprint Velocity (m/s)			
0.59	-0.04	Initial Sprint Momentum (kg*m/s)		
-0.01	0.63	0.57	Maximal Sprint Momentum (kg*m/s)	
-0.02	-0.07	0.80	0.73	Mass (kg)

5.5 Discussion

The similarity of sprinting speed but significant difference of mass and momentum between senior and junior players in Part 1 are consistent with a previously reported comparison of elite junior and senior players (Hansen, Cronin, Pickering, & Douglas, 2011) that showed differences in body mass but not sprinting speed. The differences in mass between forwards (~11 kg) and backs (~8kg) in Part 1 could indicate that this is a normal amount of mass for junior players to put on as they progress into senior rugby and they do so without increasing sprinting speed. The differences in mass and momentum between the two age groups could also have been skewed by junior players who don't have the frame to carry large amounts of muscle mass and will not progress onto senior rugby. Height was equivalent between the two groups but skeletal dimensions were not measured so this is unknown. The junior players

transitioning into senior rugby did put on mass over two years (4.4 kg) but it was much less than the differences between the two age groups in Part 1.

The cross-sectional data from Part 1 and the study of Hansen colleagues (Hansen et al., 2011) might cause coaches to conclude that speed isn't improved past 19 years of age since there was no difference in speed between juniors and seniors. The data from Part 2 of this study provides strong evidence that sprinting speed, sprint momentum and mass can all be improved with senior and junior players but junior players do have a greater window of adaptation for developing these qualities. No differences at any of the time points were detected between the Senior and Junior groups but the differences in effect sizes of the groups' shows that the Senior group was near exhausting their potential of speed and sprint momentum improvement. The Junior group made greater changes in the different sprint qualities when compared to the Senior group with the exception of ISV which was similar between the two groups (Table 7, Figure 7). These results show that large changes can be made in all of the different sprint qualities in junior players transitioning into senior rugby but the greatest changes can be made in Maximal Sprint Momentum. The strength and speed training (Table 6) that all of the players undertook likely influenced the athletes' ability to increase sprinting speed and sprint momentum. The heavy squatting, pressing and pulling exercises were likely helpful for increasing body mass (Appleby et al., 2012; Baker et al., 1994) and the emphasis on power exercises (Baker et al., 1994; Harris et al., 2000; Rimmer & Sleivert, 2000; Tricoli et al., 2005) and sprint specific training methods (Paradisis & Cooke, 2006; D. West et al., 2013) were likely able to improve the ability to develop the large but brief forces (Miller et al., 2012; Weyand & Davis,

2005) necessary for maximal speed sprinting. Improving sprint momentum is likely somewhat more complex than improving sprinting speed as there are simultaneous goals of increasing muscle mass but improving the ability to develop mass specific forces in a briefer time period. It could be inferred from the improvements in sprint momentum and sprinting velocity that the strength and speed exercises used in this study, at least in Junior players, are successful for this. The smaller improvements in Senior players in the first year and negligible improvements in the second year may indicate a few different things. It may indicate that the technique and neuro-muscular changes that can improve sprinting speed (Ross, Leveritt, & Riek, 2001) were possibly exhausted in these athletes and no further improvements could be made. Alternatively, the exercises or training frequencies were inadequate for improving performance. Another possibility is that the extensive training background of the athletes may mean that larger gains must be made in training activities to observe noteworthy gains in sprint activities.

A hypothesis of this study was that body mass would negatively affect sprinting speed. Body mass in Part 1 was found to have a stronger negative association with Maximal Sprinting Velocity (r=-0.68) than with Initial Sprinting Velocity (r=-0.52) (Figure 9). This finding is in agreement with research that suggests that Maximal Sprinting Velocity is limited by the ability to develop mass specific forces in a briefer period of time (Weyand et al., 2010) but higher body masses negatively affect the ability to develop mass specific forces (Scholz, Bobbert, & Knoek van Soest, 2006). The mass of the players in Part 1 of the current study (101.7 ± 11.8 kg) was considerably higher than the narrow range of body masses (77.0 ± 6.6 kg) reported by Uth (Uth, 2005). If speed

was the only key physical ability for rugby players, than the implication would be that players should focus on lowering their body mass. The small changes in mass of the players over two years, however, did not negatively affect their sprinting velocity (Tables 8 and 10) so these results would support the idea that small gains in mass can be made without compromising improvements in sprinting speed. The correlations between the changes in mass with ISV (r = -0.02) and MSV (r = -0.07) over two years were very weak which means that it is a safe assumption that increasing muscle mass to increase sprint momentum, will not negatively affect sprinting velocity.

Given the number and intensity of collisions in rugby, maximizing sprint momentum likely needs be a key focus for training rugby players. In Part 1, a very large correlation (Figure 9) was found between mass and both ISM (r = 0.92) and MSM (r = 0.84). It could be concluded from this that there is a compromise between maximizing sprint momentum and maximizing sprinting velocity as mass positively affects one (momentum) and negatively affects the other (velocity). The longitudinal data from Table 5 indicates that increasing mass has the greatest effect on increasing ISM (r = 0.80) and MSM (r = 0.73) but the increases in momentum also correspond to increases in ISV (r = 0.59) and MSV (r = 0.63). This means that the sprint momentum of elite rugby players can be increased by developing both body mass and sprinting speed. It may be possible that excessively increasing body mass will negatively affect sprinting speed but positively affect sprint momentum. Maximizing momentum through increasing body mass is likely important for players whose position involves ball carrying in situations where contact is unavoidable (Tight 5 players etc.) and maximizing sprinting speed by minimizing body mass is more important for players

where carrying a ball at maximal speed is normal and contact is somewhat avoidable (wingers etc.). This is supported by the fact that in Part 1, Forwards were slower for both Initial Sprint Velocity (mean difference: -0.28 m/s, $p < 0.0001$, $d = 1.04$) and Maximal Sprint Velocity (-0.72 m/s, $p < 0.0001$, $d = 1.4$) but had higher levels of Initial Sprint Momentum (77 kg*m/s, $p < 0.0001$, $d = 1.68$) and Maximal Sprint Momentum (88 kg*m/s, $p < 0.0001$, $d = 1.45$). The relationship between sprint momentum, body mass and sprint velocity would suggest that positional ideal standards should be set and all three scores need to be considered when testing.

Given the importance of sprint momentum for rugby union, it would be beneficial for future research to assess the impact of players improving sprint momentum. It would be worthwhile to know if the ability to gain mass and increase sprint momentum differentiates players who are successful in advancing to higher levels of competition from their peers who do not progress to higher levels. Additionally, it would also be interesting to know whether an increase in sprint momentum leads to individual improvements in performance during games. For instance, an off-season training program resulting in an increase in sprint momentum could lead to more effective tackles while on defence and more tackle breaks (Wheeler & Sayers, 2009) while on offense during the following season.

5.6 Practical Applications

Improving sprint momentum is likely a key component of physical preparation for rugby. Monitoring sprint momentum, and not just sprinting speed, should be a key focus for strength and conditioning coaches working with rugby players. Measuring sprint times with 10 m splits allows for coaches to consider both sprinting speed and

sprint momentum qualities. This allows for coaches to track meaningful changes in performance while considering improvements in both lean body mass and sprinting speed. Positional standards for both momentum and speed should be developed and be set as targets when planning training programs. The window for adaptation in developing sprint momentum and sprinting speed is likely greater for players in their late teens and early twenties when compared with players in their mid to late twenties. Developing sprint momentum and sprinting speed should thus be a key focus with this age group. In order to increase sprint momentum, strength training likely needs to consist of exercises that will increase both muscular hypertrophy and power. These exercises also need to be combined with different sprint training methods so an increase in body mass does not negatively affect sprinting speed.

Chapter 6

Were Height and Mass Related to Performance at the 2007 and 2011 Rugby World Cups?

Barr, Matthew J., Sheppard, Jeremy M., and Newton, Robert U., Were Height and Mass Related to Performance at the 2007 and 2011 Rugby World Cups?, *International Journal of Sport Science and Coaching*, 9, 4, 671-680, 2014.

6.1 Abstract

It has previously been reported that there are trends for height and mass in rugby players to be greater with higher levels of competition and historical increases over time are greater than the rates of increase seen in the normal population. The purpose of this study was to examine the importance of height and mass on performance in international rugby by analyzing final pool rankings at the 2007 and 2011 Rugby World Cups (RWC). The 2007 and 2011 RWCs both had four pools of five teams. Each team would play four games in the pool stages and points were given for wins, ties, scoring four or more tries and losing by less than seven points. The points accumulated from this system were used to examine the influence of height and mass on performance. Teams were subdivided into groups (1^{st}, 2^{nd}, 3^{rd}, 4^{th} or 5^{th}) depending on final rankings in the pool stages. An ANOVA and Pearson's correlation were used to compare the influence of height, mass and Body Mass Index on final pool rankings and points accumulated in each of the two tournaments. Of all of the anthropometric measurements considered, the height and mass of forwards seem to be the best indicators of team performance.

6.2 Introduction

A notable trend over the history of rugby union has been the increase in the average size of players, exceeding the rate of increase in the general population (Olds, 2001). Height and mass are both noted to be higher in international level players when compared to amateur players (Holway & Garavaglia, 2009). Differences in mass between professionals and amateurs are likely related to selection of larger players and also by the large amount of time dedicated to strength training (Brooks et al., 2008) necessary for players to progress up to higher playing levels (Argus, Gill, & Keogh, 2011). The difference in mass is also certainly related to the advantage it provides in rucks, tackles and scrums. The large number of heavy contact situations in elite rugby where the ball is contested certainly favours heavier players and it is likely the driving force behind the size increase. The average number of tackles and rucks in games dramatically increased from the mid-1990s to the early 2000s when rugby union transitioned from an amateur sport to a professional sport (Eaves, Hughes, & Lamb, 2005; Quarrie & Hopkins, 2007).

Scrums are another physical contest where larger players likely have a physical advantage. A strong correlation between the mass of an individual and the amount of force they can produce in a scrum has previously been demonstrated (Quarrie & Wilson, 2000). The ability of a forward pack to combine heavy mass and a synchronized push is what produces large pack scrummaging forces (Quarrie & Wilson, 2000). The average number of scrums in rugby games saw a large reduction from the late 1980s to the early 2000s (Eaves et al., 2005; Quarrie & Hopkins, 2007) but they remain a key aspect of the game. In fact, the amount of scrums lost has previously

been shown to be a strong discriminator between winning and losing teams in the European Six Nations competition (Ortega et al., 2009).

The greater heights of international players may partially be explained by the fact that it is easier to carry more mass on a taller frame but it likely is also related to aerial contests for the ball, particularly in the forwards. Lineouts lost was another area that discriminated between winning and losing teams in the European Six Nations (Ortega et al., 2009). Lineouts are an aerial battle between two jumpers, being lifted by two teammates each, resulting in one of the jumpers catching the ball 3 to 3.5 meters above the ground (Sayers, 2011). The height of the jumpers and lifters, in addition to their jumping and lifting ability, would contribute to the peak height that the ball can successfully be caught at. This would possibly confer an advantage during lineouts to a team with taller players.

The influence that height and mass have on game outcomes and performances in competitions has not been examined in great depth. Sedeaud and colleagues (Sedeaud et al., 2012) took the average mass and height of all teams participating in Rugby World Cups between 1987 and 2007. They found that on average, forwards and backs from teams that make the knockout rounds are taller and heavier than the teams that did not advance. Given the rapid development in rugby over the past 15 years it is unclear whether the size advantage is still a contributing factor to success or whether that gap has closed between teams at the international level. Presently, there is typically a large disparity in results in international rugby, particularly between the top five teams and teams ranked between 10th and 20th in International Rugby Board world rankings ("International Rugby Board World Rankings," n.d.). Games between

these two groups typically result in heavy one-sided losses for the lower ranked teams ("International Rugby Board World Rankings," n.d.). It is unclear if height and mass are contributing factors to these one-sided results. The purpose of the present study is to determine if mass and height could partially explain the disparity of results for teams in the modern professional era of international rugby.

6.3 Methods

6.3.1 Data collection

In the weeks prior to the 2011 and 2007 Rugby World Cup tournaments, each of the 20 teams participating submitted their tournament rosters with the reported height and mass of each player included. Height and mass were recorded from individual player profiles on the official tournament websites of the 2007 and 2011 Rugby World Cups (rwc2007.irb.com and rugbyworldcup.com). A limitation of the study design is that data were reported by the teams and not the same person using identical methods and instruments. Information was available in the public domain so informed consent was not necessary. The study design was also reviewed and approved by an Institutional Review Board. Body Mass Index (BMI; kg/m^2) was calculated for each player based on their height and mass. The individual height, mass and BMI scores were reported for each starting lineup in the 2007 (n=300) and 2011 (n=300) tournaments were kept for analysis.

The 2007 and 2011 Rugby World Cups (RWC) both had four pools of five teams. Each team would play four games in the pool stages and final pool rankings determined whether or not teams advanced to the knockout stages. The 2007 and

2011 RWC tournaments both used the same format to decide ranking during the pool stages. A team was given four points for a win, two points for a tie, one point for scoring four or more tries and one point for a loss by seven or fewer points. The results of this points scoring system was then used to analyze the influence the height and mass on performance.

To analyze the potential effect of mass, height and BMI, all of the individual player measures were sub-categorized by year of tournament (2007 or 2011), the final pool placing (1^{st}, 2^{nd}, 3^{rd}, 4^{th} or 5^{th}) of their team in that tournament and by their position (forward or back). The average BMI, mass and height of forwards, backs and team was also calculated for each country competing. The 2007 and 2011 RWCs were calculated separately when determining team averages.

6.3.2 Statistical analysis

In the first part, two way ANOVAs (tournament x pool placing) were used to compare the groups for mass, height and BMI of the team, forwards and backs. When a significant F value was found, Fisher's post hoc analysis was used to identify between group differences. An alpha of $P \leq 0.05$ was applied for all statistical measures. Pearson's correlations with a 90% confidence interval were used to calculate the relationships between the points teams accumulated during the pool stages and average mass, height and BMI for the team, forwards and backs. When a variable's 90% confidence interval was completely positive, the linear regression equation of the relationship between that variable and tournaments points was determined. The magnitude of correlation was considered trivial for being <0.1, small for being ≥0.1 and <0.3, moderate for being ≥0.3 and <0.5, large for being ≥0.5 and <0.7, very large for

being ≥0.7 and <0.9, and nearly perfect for >0.9 (Hopkins, 2011). Effects sizes (Cohen's d) of the differences between tournaments are listed with the magnitude of difference considered being trivial for being <0.2, small for ≥0.2 and <0.6, moderate for ≥0.6 and <1.2 and large for ≥1.2 (Hopkins, 2011). All statistics were calculated with XLSTAT Pro (XLSTAT, New York, NY, USA).

6.4 Results

Differences between the 2007 and 2011 RWC tournaments are presented in Table 1 and differences between the groups according to pool placing and presented in Table 2. ANOVA results for forward height and mass are played in Figure 10 and 11. Pearson's correlations between group stage team points and height, mass and BMI (team, forwards, and backs) are displayed in Table 3. Average height, mass and BMI for each position of the four semi-final teams are displayed in Table 4. The linear regression equations predicted that an increase in the average forward mass of 2.9 kg and increase in forward height of 1.4 cm is equivalent to four points (one win).

Table 11: Average (±SD) height, mass and Body Mass Index scores for starting lineup of teams at the 2007 and 2011 Rugby World Cup. In addition to the team as a whole, teams were subdivided into forwards and backs. P values, as calculated by an ANOVA and a Tukey's post hoc analysis, are listed below each group to determine differences between the tournaments.

	Height (cm)			**Mass (kg)**			**BMI (kg/m^2)**		
	Forwards	**Backs**	**Team**	**Forwards**	**Backs**	**Team**	**Forwards**	**Backs**	**Team**
2007 RWC	1.89 ± 0.08	1.82 ± 0.05	1.86 ± 0.07	110.4 ± 7.9	91.5 ± 7.9	101.6 ± 12.3	30.8 ± 2.7	27.5 ± 1.7	29.3 ± 2.8
2011 RWC	1.90 ± 0.07	1.84 ± 0.04	1.87 ± 0.06	111.6 ± 6.6	92.3 ± 6.9	102.6 ± 11.7	30.9 ± 2.4	27.4 ± 1.5	29.2 ± 2.7
P value	*P=0.245*	*P=0.014*	*P=0.04*	*P=0.14*	*P=0.34*	*P=0.30*	*P=0.88*	*P=0.36*	*P=0.80*
effect size	*d=0.12*	*d=0.40*	*d=0.14*	*d=0.15*	*d=0.10*	*d=0.08*	*d=0.03*	*d=0.05*	*d=0.03*

Table 12: Correlation and 90% confidence intervals between points accumulated during the pool stages of 2007 and 2011 Rugby World Cups and anthropometric measures.

	Mass			**Height**			**BMI**		
	Forward	**Back**	**Team**	**Forward**	**Back**	**Team**	**Forward**	**Back**	**Team**
2011 RWC	*r=0.50*	*r=0.38*	*r=0.48*	*r=0.64*	*r=0.31*	*r=0.58*	*r=0.03*	*r=0.14*	*r=0.11*
90% Upper Interval	*0.74*	*0.66*	*0.73*	*0.82*	*0.62*	*0.79*	*0.40*	*0.49*	*0.47*
90% Lower Interval	*0.15*	*0.00*	*0.12*	*0.34*	*-0.08*	*0.26*	*-0.35*	*-0.25*	*-0.28*
2007 RWC	*r=0.48*	*r=0.28*	*r=0.40*	*r=0.49*	*r=0.48*	*r=0.54*	*r=-0.01*	*r=0.12*	*r=0.13*
90% Upper Interval	*0.83*	*0.6*	*0.68*	*0.73*	*0.73*	*0.76*	*0.37*	*0.48*	*0.49*
90% Lower Interval	*0.12*	*-0.11*	*0.02*	*0.14*	*0.12*	*0.2*	*-0.39*	*-0.27*	*-0.26*

Table 13: Average (±SD) height, mass and Body Mass Index scores for starting lineups of teams at the 2007 and 2011 Rugby World Cup. In addition to the team as a whole, teams were subdivided into forwards and backs. Teams that finished 1st in the pool stages of either tournament were grouped together, teams that finished 2nd together etc. Significant differences, as calculated by an ANOVA and Tukey's post hoc analysis, with other groups are denoted below each group score by the group that it is significantly different with. *P<0.05, **P<0.01, ***P<0.0001

	Height (m)			**Mass (kg)**			**BMI (kg/m^2)**		
	Forwards	**Backs**	**Team**	**Forwards**	**Backs**	**Team**	**Forwards**	**Backs**	**Team**
1st Place	1.91 ± 0.06 5th*, 4th*	1.83 ± 0.04 5th*,4th*	1.88 ± 0.06 5th*, 4th*	112.6 ± 5.8 5th**	92.3 ± 6.0 5th*	103.1 ± 11.7 5th*	30.9 ± 2.5	27.3 ± 1.4	29.2 ± 2.7
2nd Place	1.90 ± 0.07	1.82 ± 0.05	1.87 ± 0.07	111.7 ± 7.1 5th*	93.2 ± 7.0 5th**	103.1 ± 11.6 5th*	30.9 ± 2.2	27.9 ± 1.4 5th**	29.4 ± 2.2
3rd Place	1.90 ± 0.07	1.83 ± 0.05 5th*,4th*	1.87 ± 0.07 5th*	111.5 ± 7.6	94.0 ± 8.5 5th**, 4th*	103.3 ± 11.9 5th*	30.8 ± 2.6	27.8 ± 1.7 5th**	29.4 ± 2.7
4th Place	1.89 ± 0.06 1st*	1.82 ± 0.04 1st*,3rd**	1.86 ± 0.06 1st*	110.1 ± 7.3	90.6 ± 8.2 3rd*	101.0 ± 12.4	30.9 ± 2.7	27.3 ± 1.8	29.2 ± 2.9
5th Place	1.88 ± 0.07 1st*	1.82 ± 0.06 1st*,3rd*	1.85 ± 0.07 1st*	109.1 ± 8.2 1st**,2nd*	89.3 ± 6.6 1st*, 2nd**, 3rd**	99.9 ± 12.4 1st*,2nd*, 3rd*	30.7 ± 3.1	27.0 ± 1.42	29.0 ± 3.1

Table 14: Average reported anthropometric scores of semi-finalists of the 2011 Rugby World Cup. Range of scores is listed in parentheses.

	Mass (kg)	**Height (m)**	**BMI (kg/m²)**
Loose Head Prop	117.5 (105-125)	1.85 (1.80-1.88)	34.3 (32.4-35.4)
Hooker	107 (101-112)	1.82 (1.81-1.86)	32.0 (30.8-33.3)
Tight Head Prop	117.7 (115-120)	1.85 (1.83-1.89)	34.4 (32.8-35.8)
Loose Head Lock	117.5 (115-120)	2.00 (1.95-2.06)	29.3 (27.6-30.2)
Tight Head Lock	116.5 (114-122)	1.97 (1.95-2.00)	29.9 (28.8-31.4)
Blindside Flanker	111 (106-116)	1.95 (1.93-1.97)	29.1 (27.3-30.2)
Openside Flanker	102 (95-106)	1.86 (1.81-1.88)	29.5 (26.9-30.8)
No.8	110.5 (108-117)	1.92 (1.88-1.97)	29.8 (29.0-30.8)
Scrumhalf	91.7 (85-101)	1.83 (1.78-1.91)	27.3 (25.7-30.3)
Flyhalf	87.7 (80-96)	1.81 (1.75-1.86)	26.6 (24.7-28.0)
Left Wing	89.5 (89-101)	1.79 (1.70-1.90)	27.9 (26.8-29.0)
Inside Center	99.7 (91-110)	1.85 (1.81-1.93)	28.9 (26.6-32.0)
Outside Center	98 (88-105)	1.86 (1.78-1.94)	28.3 (27.5-30.4)
Right Wing	92.7 (88-105)	1.83 (1.78-1.92)	27.6 (26.3-28.5)
Fullback	92.2 (83-98)	1.82 (1.78-1.86)	27.8 (26.2-29.6)

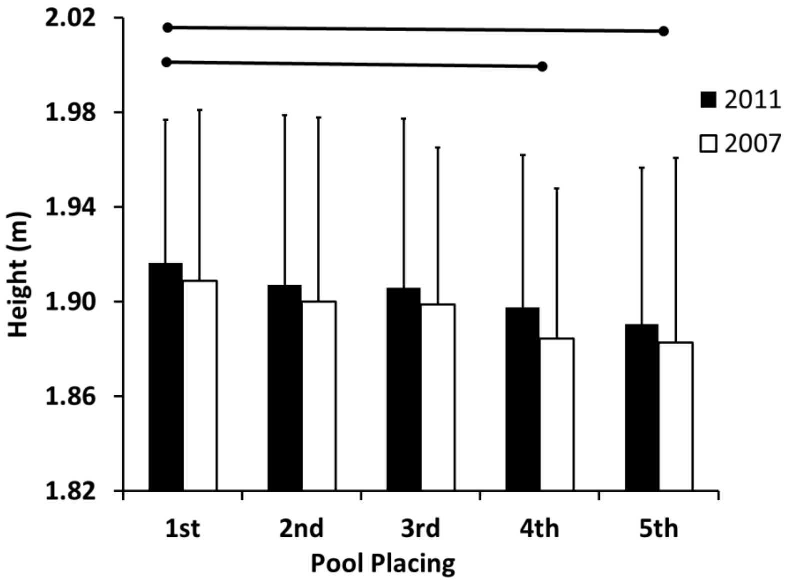

Figure 10. Average forward height of teams finishing 1st to 5th in the pool stages at the 2007 and 2011 Rugby World Cups. Black bars represent the 2011 Rugby World Cup and the white bars represent the 2007 Rugby World Cup. Error bars denote standard deviation. Lines denote statistically significant differences between pool placing groups combined from 2007 and 2011 Rugby World Cups.

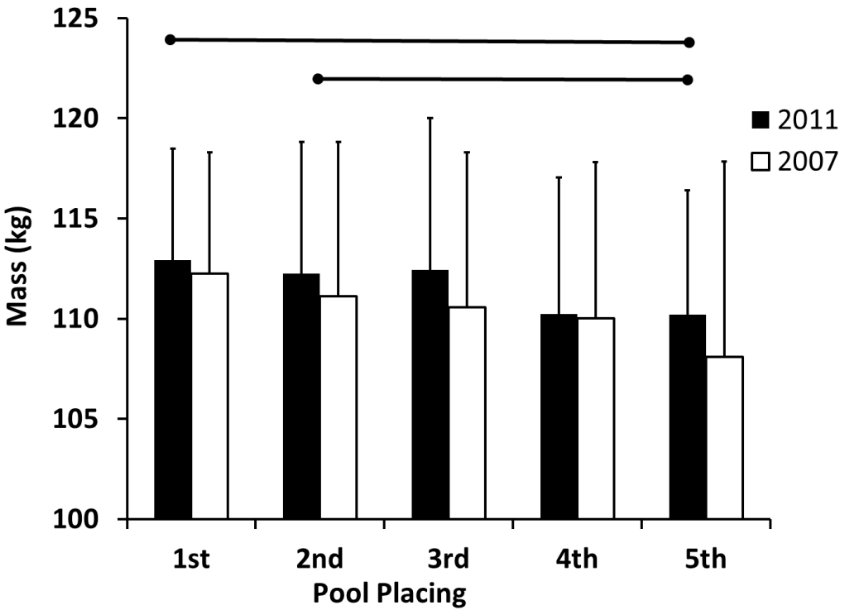

Figure 11. Average forward mass of teams finishing 1st to 5th in the pool stages at the 2007 and 2011Rugby World Cups. Black bars represent the 2011 Rugby World Cup and the white bars represent the 2007 Rugby World Cup. Error bars denote standard deviation. Lines denote statistically significant differences between pool placing groups combined from 2007 and 2011 Rugby World Cups.

6.5 Discussion

The mass and height of forwards would seem to have the strongest influence on team performance. The teams that came in 1st in the pool stages had, on average, significantly taller forwards than 4th and 5th place teams (Figure 10, Table 11) and teams that came in 1st or 2nd had significantly heavier forwards than teams that came in 5th (Figure 11, Table 11). There was a large correlation between team points accumulated in the pool stage with forward height (r=0.64) as well as with forward mass (r=0.5). A similar relationship was also seen in the 2007 tournament but the correlation were moderate for height (r=0.49) and mass (r=0.48). The 90% confidence interval (Table 3) of points accumulated in the pool stages in both tournaments were also positive for both of these measures, suggesting that taller and heavier forwards are important to tournament success at this level. The linear regression equations from the 2011 tournament predicted that an increase in the average forward mass of 2.9 kg and increase in forward height of 1.4 cm is equivalent to four points (one win). The trivial increases in mass (111.6 kg vs 110.4 kg, P=0.14, d=0.15) and height of forwards (1.90 m vs 1.89 m, P=0.24, d=0.12) from 2007 to 2011 would suggest that the size of international players is fairly stable but it may highlight a continued slow evolution towards heavier and taller players.

The relationship between height and mass with performance in the backs was not as clear as it was with the forwards. The 1st place teams were taller and heavier than the teams that came in 5th (Table 1). The correlations between back height and mass with performance were small to moderate and not consistent between tournaments with the 90% confidence intervals overlapping zero for one of the

measures in both of tournaments (Table 12). Similar to the forwards, BMI had a very weak correlation but interestingly there were some differences favouring the higher placed groups with the notable exception that there was no difference between the 1st placed group and all the others (Table 11). The lack of differences in the forwards but differences in the backs might suggest that teams might use different strategies in putting mass on their players. The lack of differences in the forwards might suggest that all teams try to maximize the muscle forwards can carry on their frame but some teams might emphasise this less with the backs. This may be related to teams trying to keep their backs lighter to enhance sprinting speed while others may be trying to put more muscle on their backs to dominate collisions. Like the forwards, the differences between tournaments were trivial for changes in mass but there was a small effect size for change in height (1.84 m vs. 1.82 m, P<0.014, *d*=0.4).

Both height and mass seemed to be predictors of performance at the 2007 and 2011 RWCs (Table 11 and Figures 10 and 11). It is possible that it is desirable to have large backs and large forwards for different reasons. Having large forwards may be an advantage for scrums and lineouts (Ortega et al., 2009; Quarrie & Wilson, 2000). Given that forwards also spend more time in rucks and mauls (Austin et al., 2011b; Deutsch et al., 2007; Duthie, Pyne, & Hooper, 2005) it likely is much more important to have large forwards than backs, who sprint much more than forwards (Austin, Gabbett, & Jenkins, 2011a; Deutsch et al., 2007; Duthie, Pyne, Marsh, et al., 2006). Having large backs may provide some advantage during collisions (Wheeler & Sayers, 2009) but it is likely that speed and other evasive skills are more important (Sayers & Washington-King, 2003; Smart et al., 2014). One possible advantage of selecting taller backs is that

they may have an advantage during an aerial contest for the ball but there is also the likelihood that taller players are better able to carry muscle mass without compromising sprinting speed, due to the relationship between height, stride length and the ability to develop forces relative to body mass (Uth, 2005). In other words, a taller athlete can likely carry more muscle mass than a shorter athlete without compromising sprinting speed because of a longer stride length (Hunter, Marshall, & McNair, 2004; Uth, 2005).

When examining historical data and body types of elite sprinters it would appear that there may exist an optimal range of size for sprinters (Uth, 2005; Watts et al., 2011; Weyand & Davis, 2005) that is not likely optimal for rugby players. The cluster of elite sprinters around a certain mass and Body Mass Index (BMI) suggests that the ability to develop mass specific forces necessary for successful sprinting likely has a curve that peaks around athletes with a mass of 77kg and a BMI of between 23 and 24 (Uth, 2005). This is much smaller than previously reported anthropometric measurements of professional rugby forwards and still even smaller than backs (Duthie, Pyne, Hopkins, et al., 2006) who need to display high sprinting speeds for their position (Duthie, Pyne, Marsh, et al., 2006; Duthie et al., 2005). As important as speed is for rugby (Austin et al., 2011b; Duthie, Pyne, Marsh, et al., 2006; Sayers & Washington-King, 2003; Smart et al., 2014) the amount of contact in games (Eaton & George, 2006) suggest that mass is important. Given the competing demands of trying to maximise both sprinting speed and mass, determining an ideal size for players becomes a compromise between the relative importance of how fast a player needs to be and how heavy they need to be for collisions. With this in mind, it could be

suggested that maximizing momentum (combination of speed and mass) is likely more important than just speed for rugby players. Sprint momentum has previously been noted to discriminate between playing level in amateur club rugby players (Quarrie et al., 1995) but this has never been examined in elite professional players.

It was previously noted that there was a large increase in the size of rugby players competing in the initial RWC in 1987 up to RWC in 2007 (Sedeaud et al., 2012). There were small differences in height and mass between the 2007 and 2011 tournaments (Table 1). The differences seem much smaller than the large increases that were seen in the RWCs during the 1980s and 1990s (Sedeaud et al., 2012). Professionalism was likely the major reason for the large increases in player size because it allowed more time to be dedicated to strength training. This was likely combined with better nutritional practices and the implementation of ergogenic aids. The amount of collisions from rucks and tackles greatly increased in the early years of professionalism (Eaves et al., 2005; Quarrie & Hopkins, 2007) and it was hypothesized that changes in maul laws, that awarded scrums to a team that is able to successfully hold up the other team in a tackle, led to the increase in the amount of tackles and rucks(Quarrie & Hopkins, 2007). The rule changes either put pressure on teams to develop larger players or the increase in collisions was possibly a by-product of developing larger and fitter players. Another key rule change that also happened just prior to professional era was the addition of tactical substitutions. This potentially could have impacted the make-up of teams by allowing them to include players who weren't now required to play the full 80 minutes and potentially favour larger players who were more effective playing for shorter periods of time. The sizes of players listed

in Table 13 (semi-finalists at the 2011 RWC) may represent the current standard for world class international players currently but it is possible that the optimal size for players may continue to increase if rules are changed, training methods are improved or there is an increased emphasis on talent identification of young players with potential for large size.

6.6 Conclusion

Having tall and heavy forwards seems to be important for performance in international rugby. Height and mass for backs does not seem to be as important of a discriminator, but still appears to be a relevant consideration in Rugby World Cups. In addition to competence at positional specific rugby skills, identifying young players with adequate height for international rugby is likely important for talent development. Training methods that maximize speed, strength and jumping ability while increasing muscle mass to achieve an optimal position-specific body mass are likely to be paramount for the development of elite rugby players. Elite rugby union is complex and multifactorial but selecting tall and heavy players will likely continue to be very important for performance in international rugby. Developing a large pool of talented players who meet the anthropometric requirements of international rugby is likely a key factor of success at the Rugby World Cup.

Chapter 7

The Transfer Effect of Strength and Power Training to the Sprinting Kinematics of International Rugby Players

Barr, Matthew J., Sheppard, Jeremy M., Agar-Newman, Dana and Newton, Robert U., The transfer effect of strength and power training to the sprinting kinematics of elite rugby players, *Journal of Strength and Conditioning Research*, 28, 9, 2585-2596, 2014.

7.1 Abstract

Increasing lower body strength is often considered to be important for improving the sprinting speed of rugby players. This concept was examined in a group (n=40) of international rugby players in a two part study. The players were tested for body mass (BM), one repetition maximum power clean (PC) and front squat (FS), as well as triple broad jump (TBJ) and broad jump (BJ). In addition, speed over 40 m was tested, with timing gates recording the 0-10 m and 30-40 m sections in order to assess acceleration and maximal velocity. Two video cameras recorded the two splits for later analysis of sprinting kinematics. The players were divided into a fast group (n=20) and a slow group (n=20) for both acceleration and maximal velocity. In the second part of the study, a group (n=15) of players were tracked over a one year period to determine how changes in strength corresponded with changes in sprinting kinematics. The fast groups for both acceleration and maximal velocity showed greater levels of strength (d=0.5 – 1.8), lower ground contact times (d=0.8 – 2.1), and longer stride lengths (d=0.5 – 1.3). There was a moderate improvement over 1 year in PC/BM (0.08 kg/kg, P=0.008, d=0.6) and this had a strong relationship with the change in maximal velocity stride length (r=0.70). Acceleration stride length also had a large improvement over one year (0.09 m, P=0.003, d=0.81). While increasing lower body strength is likely important for increasing sprinting speed of players with low training backgrounds, it may not have the same effect with highly trained players.

KEY WORDS: exercise specificity, ground contact time, maximal sprinting velocity

7.2 Introduction

Speed is commonly considered to be a highly valuable ability in rugby union (Duthie, Pyne, Marsh, et al., 2006) and the selection of different training methods to improve sprinting speed is an important part of training rugby players (Duthie, 2006). Improving leg strength relative to body mass has been suggested as a way of positively improving the sprinting speed of athletes (Comfort, Haigh, et al., 2012; Duthie, 2006). A rationale for this is that decreasing ground contact time, particularly at maximal velocity, is considered the most important kinematic change for improving sprinting speed (Weyand et al., 2010). An increase in force production must occur if a decrease in ground contact time is to happen (Weyand et al., 2010). The vertical velocity of the center of gravity, which has been reported (Mann, 2011) to change from -0.5 m/s to 0.5 m/s during the maximal velocity sprinting stride, requires high force production. Decreasing ground contact time and maintaining this change in vertical velocity would require a further increase in average force production (Mann, 2011; Weyand et al., 2010). For example, a 100kg rugby player who shortens his ground contact time from 0.12 s to 0.10 s must hypothetically increase the average vertical force during his stance phase from 1814 N (185 kg) to 1981 N (202 kg) if he is to raise his center of gravity 0.5 m/s during each stride (Mann, 2011). If this player had a typical maximal velocity stride length of 2.2 m and a flight time of 0.12 s, and maintained these with the above reduction in ground contact time, he would hypothetically increase his maximal velocity from 9.2 m/s to 10 m/s. A change of this magnitude would be an improvement in an international or professional rugby player's speed from average to exceptional (Duthie, Pyne, Marsh, et al., 2006; Higham et al., 2013). Selecting

appropriate strength and power exercises that help increase the ability to develop force relative to body mass and decrease ground contact time have been suggested to be a highly important aspect of training program design for improving sprinting speed (Mann, 2011; Stone, Stone, & Sands, 2007; Weyand et al., 2010).

Ground contact times are much longer during initial and mid-acceleration phases when compared to maximal velocity (Barr et al., 2013). This indicates that they could be considered different speed qualities (Barr et al., 2013). The differences in ground contact times between speed qualities may also mean that different strength qualities (maximal strength, explosive strength, reactive strength etc.) may be more important at different phases of a sprint, based on the time available to develop force (Wilson et al., 1996). Previous studies that have examined speed and strength quality relationships have found strong correlations between sprinting speed and maximal strength, explosive strength and reactive strength (Baker & Nance, 1999; Barr & Nolte, 2011; Brechue et al., 2010; Comfort, Bullock, et al., 2012; Hennessy & Kilty, 2001; Hori et al., 2008; Mero, 1985; Peterson et al., 2006; Sleivert & Taingahue, 2004; Wisloff et al., 2004). Eight of these studies timed an acceleration component (~10 m), seven timed a longer sprint distance (~40 m) and only three measured a maximal sprinting velocity. Only one of these studies measured stride length and stride rate, with no study has examining the relationship between ground contact time and lower body strength.

Training studies investigating programs which incorporate maximal strength or explosive strength training exercises have found improvements in the sprinting speeds of athletes (Delecluse et al., 1995; Harris et al., 2000; Hermassi et al., 2011; McEvoy &

Newton, 1998). Rimmer and Sleivert (Rimmer & Sleivert, 2000) noted an improvement in sprinting speed, with a corresponding decrease in ground contact time, after a program of plyometric training. There is little other research, however, examining the relationships between changes in strength and sprinting kinematics. The current study aimed to develop a greater understanding of the relationship between changes in strength qualities and changes in the sprinting kinematics of elite rugby players. It is hypothesized that stronger and more powerful players will display higher velocities, higher stride rates, longer stride lengths, and lower ground contact times than their weaker peers. It is expected that the relationship between strength qualities and sprinting kinematics would be different between acceleration and maximal velocity phases and between fast and slow groups. Lastly, it is hypothesized that long term changes in strength qualities would correspond with improvements in sprinting kinematics as predicted by cross-sectional data.

7.3 Methods

7.3.1 Experimental Approach to the Problem

In order to understand how the development of lower body strength qualities affects sprinting speed, the study was divided into two parts. The 1st part consisted of a causal-comparative cross sectional design whilst the 2nd part of the study was a longitudinal quasi-experimental design. The 1st part of the study consisted of examining the relationship between sprinting kinematics and lower body strength qualities in a group of rugby players (n=40). The group was twice divided into fast (n=20) and slow (n=20) groups based on sprinting speed for both the 0-10 m and 30-40 m segments. The 2nd part of the study consisted of tracking a group of elite (n=15)

rugby players over a year period to determine if increasing leg strength qualities was associated with an improvement in sprinting kinematics.

7.3.2 Participants

In Part 1, a group of players (n=40) underwent a series of assessments to characterize their sprinting ability and lower limb muscle function characteristics. The players (height = 1.84 ± 0.07 m, mass = 98.5 ± 11.9 kg, 22.2 ± 3.0 years) who participated in the study were a mix of 21 senior international rugby players, 14 under-20 national team players and 5 uncapped players belonging to a senior national team academy. The national team that all of the players were affiliated with is typically ranked 11th-15th place on the International Rugby Board world rankings. All of the players in the study, prior to the testing, had a minimum of 50 strength training and 20 sprint training sessions that were supervised by a strength and conditioning coach who gave them specific technical feedback. In Part 2, a smaller group of players (n=15) were measured at the beginning and end of a one year period using the same methods as Part 1. All of the players in Part 2 (1.84 ± 0.05 m, 100.6 ± 11.2 kg, 24.1 ± 3.4 years) played either senior 15s or 7s national team rugby during the experimental period and had a history of at least 3 years of supervised speed and strength training. All participants gave informed written consent to take part in the study which had Institutional Review Board approval.

7.3.3 Speed Assessment

Each of the players performed four 40 m sprints on an artificial field using a Brower (Utah) system with timing gates placed upon 1 m high tripods at 0 m, 10 m, 30

m and 40 m. The players began each sprint with their front foot beside a cone 0.75 m behind the first gate. The 0-10 m split was used to assess acceleration ability and the 30-40 m split was used to assess maximal velocity sprinting ability (Barr et al., 2013). Prior to the testing period, the participants undertook a 25 minute warm up that included light running, dynamic stretches and three 40 m sprints that progressively increased in intensity from 60% of maximal volitional effort to 95% of maximal effort. After warm-up, the participants were given a four minute break before they performed their first 40 m sprint and four to five minutes of passive rest after each subsequent sprint. The fastest 0-10 m split, the fastest 30-40 m split and all corresponding kinematics from those trials were kept for analysis. The 0-10 m and 30-40 m splits were converted into velocities by dividing the 10 m distance by the time taken to complete it. The velocity from the 0-10 m split was considered to be Initial Sprinting Velocity (ISV) and the 30-40 m split was considered to be Maximal Sprinting Velocity (MSV).

In order to characterize sprinting kinematics, each of the sprints was filmed using two Nikon J1 video cameras recording at 400 frames per second. Calibration markers were placed 0.5 m to either side of the run at 0 m, 6 m, 30 m and 36 m. The first camera recorded the 0-6 m section and the second camera recorded the 30-36 m section. In order to assess the sprinting kinematics of each player, stride rate, stride length, relative stride length, ground contact time and flight time were calculated (Mann, 2011) with the aid of computer software (Kinovea). A stride was considered to be the time from touchdown from one leg to the last instant before touchdown of the other leg (Mann, 2011). Stride length was determined by measuring the distance

between successive toe-off positions in each stride, with the most anterior part of the foot at toe off used as a marker for measuring stride length. Relative stride length was calculated by dividing stride length by the height of the athlete. Ground contact times were calculated by counting the number of frames (0.0025 s per frames) between touchdown and toe-off. Flight time was determined by counting the number of frames between toe-off and touchdown. Stride rate was determined by dividing one stride by the time taken to complete it (1/ground contact time + flight time). Typical error of measurement (TEM) and Interclass Correlations (ICC) were previously calculated with pilot data from two individuals experienced analyzing sprinting biomechanics in order to determine inter-rater reliability. Strong inter-rater reliability for these kinematic assessment methods were found for stride length (ICC=0.99, TEM=0.017 m), ground contact time (ICC=0.95, TEM=0.005 s), and flight time (ICC=0.84, TEM=0.003 s). Pilot data also revealed strong reliability within the testing sessions for Initial Sprinting Velocity (ICC=0.87, TEM=0.08 m/s), Maximal Sprinting Velocity (ICC=0.90, TEM=0.17 m/s), Acceleration GCT (ICC=0.75, TEM=0.005 s), Acceleration FT (ICC=0.75, TEM=0.006 s), Acceleration SL (ICC=0.85, TEM=0.026 m), Maximal Velocity GCT (ICC=0.8, TEM=0.003 s), Maximal Velocity FT (ICC=0.82, TEM=0.007 s) and Maximal Velocity SL (ICC=0.7, TEM=0.05 m).

7.3.4 Strength Assessment

Within one week of the sprint testing, the participants were tested for strength qualities by assessing broad jump (BJ), triple broad jump (TBJ), power clean (PC) and front squat (FS) in a single session. The tests were performed in the following order: BJ, TBJ, PC and FS with approximately five minutes between each exercise. Each of the

participants was given five attempts for both BJ and TBJ. The score for each of the different jump conditions was the distance between the lines that the athlete started behind and the back of their heel after they had landed. During the BJ, the participants were encouraged to jump horizontally off of two feet as far as they could and were allowed to use an arm swing while jumping. While landing the players were instructed to land in a position of deep knee flexion to maximize the horizontal distance of the jump. During the TBJ the participants were encouraged to land in the same manner but with the exception that they land and jump again with a minimal landing time after the 1st and the 2nd jumps. The longest jumps were retained for analysis. Pilot data of the jumping tests showed that they had high reliability with a TEM and CV of 0.04 m and 7% for BJ and with 0.12 m and 7% for TBJ.

When testing for a 1 repetition maximum (1RM) PC and a 1RM FS, the subjects performed 2-3 warm up sets of 3-5 repetitions below 60% followed by 1-2 repetitions at 70%, 80%, 85%, 90%, 95% and 100% of predicted 1RM. The subjects then continued to increase the weight by 2-5% until they failed. Each participant took 3-5 minutes between attempts at near maximal or maximal weights. The protocols for testing PC were that the bar had to begin from the floor and end when the athlete successfully stood up with the bar on their shoulders. The bar had to be received in the "power position" such that at no point did the long axis of their thigh drop below parallel. When testing FS, the athlete had to squat in a below parallel manner while keeping the bar on their shoulders and holding the bar in a "clean catch" position. PC and FS were expressed relative to body mass (PC/BM and FS/BM) for analyzing relative strength.

7.3.5 Training Program

All of the participants involved in Part 2 of the study were training on a full time basis at a national team training academy. Each of the participants were typically involved in approximately 8-12 weeks per year of national team duty, 24 weeks per year of club rugby, 12-16 weeks per year of pre-season training and 4 weeks of rest. Training during national team competition weeks typically involved 1-2 strength and 3-4 rugby sessions per week. Club rugby weeks consisted of 2-3 strength, 1-2 speed and 2-3 rugby sessions per week. Pre-season was 2 speed, 3-4 strength and 1-2 rugby sessions per week. Given the intense nature of rugby, each player was injured at some point of the study so that their training had to be modified but no players were injured to an extent that long term layoffs (>1 month) occurred. Each participant followed an individualized training program. Table 15 lists typical speed and strength exercises used during training sessions. When players were not involved in national team duty, each program typically went on 6-8 week cycles divided into an initial 3-4 week block emphasizing maximal strength with a second 3-4 week block emphasizing power. This was typically accomplished by altering training volumes of exercises (i.e. more back squats in Block 1 and more plyometrics in Block 2) or by replacing exercises (back squats in Block 1 and jump squats in Block 2). Speed training focused on improving acceleration in the first block of training and maximal sprinting velocity in the second block. Training during national team competition weeks was, at a minimum, focused on maintaining maximal, explosive and reactive strength.

Table 15: Typical strength and speed exercises used during training.

Speed Exercises	*Strength, Power and Plyometric Exercises*
• Flat sprints (10 - 60 m) • 3° Uphill Sprints (10 - 20 m) • Sled Sprints (5 - 15 m) • 3° Downhill Sprints (20 - 40 m) • Change of Direction Drills	• Squats (Back, Front, Split) • Presses (Bench, Military, Push, Incline) • Upper Body Pulls (Chin-up, Bent Over Row, Pull-up) • Cleans (Squat, Power, Split, Pulls, from Floor, from Hang, from Blocks) • Snatches (Power, Split, Pulls, from Floor, from Hang, from Blocks) • Jerks (Power, Split) • Weighted Jumps (Barbell, Kettlebell, Unilateral, Bilateral) • Horizontal Jumps (Broad, Mulitple Broad, Single Leg Bounds) • Eccentric Load Jumps (Drop Jumps, Eccentric Release Jumps) • Assisted Jumps • Back Exercises (Good Morning, Back Extension)
Training Volume: • 100-350 m per session total volume	*Training Volume*: • 4-6 exercises per session • 5-8 sets per exercise • 1-8 reps per set • Sessions typically concluded with abdominal exercises and small muscle group injury prevention type exercises for ankles, necks, rotator cuffs etc.

7.3.6 Statistical Analysis

In order to assess the hypothesis that faster players had superior strength and power scores than their slower counterparts, the participants were, using the median split technique, divided into a fast group (n=20) and a slow group (n=20) for both acceleration (0-10 m split) and maximal velocity (30-40 m split). Fast and slow groups were compared for anthropometric scores, strength quality scores and sprinting kinematics. Differences between the fast and slow groups were calculated with a Student's T-Test. Cohen's *d* effect sizes were calculated to characterize the differences between groups. In order to assess the relationships between the various sprinting kinematics, anthropometric, and strength quality measures in Part 1, Pearson's correlations were calculated. In Part 2, paired T-Tests were used to compare the differences in testing scores between the pre- and post-tests over the one year experimental period. To determine the transfer effect between strength and power exercises and sprinting performance, a transfer of training effect (Young, Mclean, & Ardagna, 1995; Zatsiorsky & Kraemer, 2006) was calculated according to the following formula:

$$\text{Transfer of Training Effect} = \frac{\text{Effect Size Change in Sprinting Performance}}{\text{Effect Size Change in Strength Training Exercise}}$$

Transfer of training effects were only calculated between variables that had an effect size of at least d=0.2 which is considered the smallest worthwhile difference for a team sport athlete (Hopkins, 2011). The higher the score of transfer of training effect, the more likely the training exercise positively influenced sprinting performance. Pearson's correlations were also calculated between changes in various

sprinting kinematics and strength and power scores over the one year period. The magnitude of positive correlations were classified as trivial <0.1, small 0.1 - 0.29, moderate 0.3 - 0.49, large 0.5 - 0.69, very large 0.7 - 0.89, and nearly perfect >0.9 (20). Cohen's *d* effect sizes were considered trivial 0 - 0.19, small 0.2 - 0.59, moderate 0.6 - 1.19, large 1.2 - 1.99, and very large for >2.0 (20). All statistical analyses were conducted with XLSTAT (New York, USA) software.

7.4 Results

In Part 1, 13 athletes were placed in the fast group for both the acceleration and maximal velocity analyses, 13 were in both slow groups, and there were 14 who were in one of the fast groups and one of the slow groups. Differences between the acceleration and maximal velocity groups for anthropometric measures, sprinting kinematics and strength quality measures are listed in Table 16 and 17 respectively. When comparing the fast and slow acceleration group, moderate differences for ground contact time (0.16 vs 0.17 s, d=0.8) and FS/BM (1.46 vs 1.36 kg/kg, d=0.8) were found. Large differences for PC/BM (1.30 vs 1.14 kg/kg, d=1.2), BJ (2.68 vs 2.46 m, d=1.7), and TBJ (8.44m vs 7.54 m, d=1.7). The fast and slow acceleration groups for maximal velocity showed moderate differences for stride length (2.06 vs 1.99 m, d=0.8), large differences for relative stride length (1.13 vs 1.07 m/m, d=1.3), PC/BM (1.30 vs 1.14 kg/kg, d=1.2), BJ (2.69 vs 2.45 m, d=1.8) and TBJ (8.44 vs 7.66 m, d=1.5) , and very large differences for ground contact time (0.10 vs 0.12 s, d=2.1).

The correlations between anthropometric measures and strength quality scores with sprinting kinematics for the whole group, fast group, and slow group are displayed in Figure 12 and Tables 18 and 19. Initial Sprint Velocity has similar

correlation for both the slow and fast group with PC/BM (r=0.68, r=0.67), BJ (r=0.73, r=0.66) and TBJ (r=0.72, r=0.69). The slow group, when compared to the fast group, had stronger correlations between Maximal Sprint Velocity and FS/BM (r=0.58, r=0.28), PC/BM (r=0.84, r=0.60), BJ (r=0.79, r=0.28) and TBJ (r=0.80, r=0.39). Of all the strength tests, PC/BM had the strongest relationship with acceleration ground contact time (r=-0.61, r=-0.56) and maximal velocity ground contact time (r=-0.69, r=-0.49) with the slow and fast groups.

Changes in strength and speed measurement are presented in Table 20 and the correlations between those changes are presented in Table 21. Changes in PC/BM and FS/BM had very large (r=0.70) and moderate correlations (r=0.49) with change in stride length over 1 year. Changes in FS/BM had a moderate relationship (r=0.49) with changes in Initial Sprinting Velocity. For determining transfer of training effects, PC/BM was the only strength quality measure and Acceleration Stride Length, Acceleration Ground Contact Time, and Maximal Stride Length were the only sprinting kinematics that met the criteria of at least a small (*d*=0.2) effect size change. Transfer of training effects were therefore calculated between PC/BM and Acceleration Stride Length (1.2), Acceleration Ground Contact Time (0.36) and Maximal Velocity Stride Length (0.38).

Table 16: Differences between the Fast Acceleration Group and the Slow Acceleration Group for anthropometric measures, sprinting kinematics and strength and power exercises.

	Fast Group (n=20)	*Slow Group (n=20)*	*P Value*	*Effect Size (d)*	*Magnitude*
Anthropometric					
Height (m)	1.84 ± 0.07	1.84 ± 0.06	0.88	0.04	Trivial
Mass (kg)	93.2 ± 8.9	103.8 ± 12.4	0.004	1.2	Large
Acceleration Sprinting Kinematics					
Initial Sprinting Velocity (m/s)	5.88 ± 0.13	5.48 ± 0.17	<0.0001	3.4	Very Large
Stride Rates (strides/s)	4.27 ± 0.23	4.16 ± 0.23	0.15	0.5	Small
Stride Length (m)	1.25 ± 0.08	1.21 ± 0.10	0.16	0.5	Small
Relative Stride Length (m/m)	0.68 ± 0.06	0.66 ± 0.06	0.23	0.4	Small
Ground Contact Time (s)	0.16 ± 0.01	0.17 ± 0.02	0.0345	0.8	Moderate
Flight Time (s)	0.07 ± 0.01	0.07 ± 0.01	0.2798	0.4	Small
Strength and Power					
Front Squat (kg)	138 ± 15	138 ± 15	0.97	0.01	Trivial
Front Squat/Body Mass (kg/kg)	1.5 ± 0.21	1.33 ± 0.15	0.005	0.8	Moderate
Power Clean (kg)	121 ± 11	117 ± 9	0.24	0.3	Small
Power Clean/Body Mass (kg/kg)	1.30 ± 0.13	1.14 ± 0.13	0.0004	1.2	Large
Broad Jump (m)	2.68 ± 0.12	2.46 ± 0.28	0.0007	1.7	Large
Triple Broad Jump (m)	8.44 ± 0.46	7.54 ± 0.62	0.0001	1.7	Large

Table 17: Differences between the Fast Maximal Velocity Group and the Slow Maximal Velocity Group for anthropometric measures, sprinting kinematics and strength and power exercises.

	Fast Group (n=20)	***Slow Group (n=20)***	***P Value***	***Effect Size (d)***	***Magnitude***
Anthropometric					
Height (m)	1.82 ± 0.07	1.86 ± 0.06	0.12	0.5	Small
Mass (kg)	92.2 ± 9.2	104.8 ± 11.0	0.0004	1.4	Large
Maximal Velocity Sprinting Kinematics					
Maximal Sprinting Velocity (m/s)	9.29 ± 0.29	8.36 ± 0.44	<0.0001	3.2	Very Large
Stride Rates (strides/s)	4.55 ± 0.26	4.21 ± 0.29	0.0005	1.3	Large
Stride Length (m)	2.06 ± 0.09	1.99 ± 0.14	0.06	0.8	Moderate
Relative Stride Length (m/m)	1.13 ± 0.05	1.07 ± 0.06	0.0007	1.3	Large
Ground Contact Time (s)	0.10 ± 0.01	0.12 ± 0.02	0.0001	2.1	Very Large
Flight Time (s)	0.12 ± 0.01	0.12 ± 0.01	0.76	0.1	Trivial
Strength and Power					
Front Squat (kg)	134 ± 15	141 ± 13	0.14	0.4	Small
Front Squat/Body Mass (kg/kg)	1.46 ± 0.2	1.36 ± 0.19	0.11	0.5	Small
Power Clean (kg)	119 ± 12	118 ± 8	0.69	0.1	Trivial
Power Clean/Body Mass (kg/kg)	1.30 ± 0.13	1.14 ± 0.13	0.0003	1.2	Large
Broad Jump (m)	2.69 ± 0.13	2.45 ± 0.20	0.0001	1.8	Large
Triple Broad Jump (m)	8.44 ± 0.53	7.66 ± 0.58	<0.0001	1.5	Large

Table 18: Pearson's correlations between Acceleration Sprinting Kinematics, anthropometric measures and strength and power measures. The top number is the correlation for the whole group (n=40), the middle number is the Acceleration-Slow Group (n=20) and the bottom number is the Acceleration-Fast Group (n=20).

		Height	***Mass***	***Front Squat / Body Mass***	***Power Clean / Body Mass***	***Broad Jump***	***Triple Broad Jump***
Initial Sprinting Velocity	*Group*	0.14	-0.61	0.50	0.70	0.75	0.75
	Slow	0.13	-0.54	0.21	0.68	0.73	0.72
	Fast	0.18	-0.52	0.52	0.67	0.66	0.69
Stride Rate	*Group*	-0.25	-0.42	0.50	0.51	0.32	0.36
	Slow	-0.35	-0.56	0.63	0.50	0.16	0.12
	Fast	-0.20	-0.12	0.34	0.43	0.40	0.51
Stride Length	*Group*	-0.07	-0.32	0.20	0.29	0.44	0.43
	Slow	0.14	-0.23	0.06	0.35	0.55	0.60
	Fast	-0.07	-0.35	0.27	0.36	0.49	0.47
Relative Stride Length	*Group*	-0.51	-0.56	0.40	0.44	0.36	0.38
	Slow	-0.28	-0.49	0.16	0.50	0.48	0.52
	Fast	-0.72	-0.61	0.51	0.32	0.07	0.10
Ground Contact Time	*Group*	0.45	0.67	-0.50	-0.62	-0.44	-0.43
	Slow	0.22	0.71	-0.47	-0.61	-0.30	-0.20
	Fast	0.34	0.64	-0.46	-0.56	-0.37	-0.36
Flight Time	*Group*	-0.19	-0.36	0.09	0.22	0.19	0.15
	Slow	0.05	-0.29	-0.07	0.21	0.17	0.10
	Fast	-0.10	-0.39	0.12	0.25	0.19	0.14

Table 19: Pearson's correlations between Maximal Velocity Sprinting Kinematics, anthropometric measures and strength and power measures. The top number is the correlation for the whole group (n=40), the middle number is the Maximal Velocity-Slow Group (n=20) and the bottom number is the Maximal Velocity-Fast Group (n=20).

		Height	***Mass***	***Front Squat / Body Mass***	***Power Clean / Body Mass***	***Broad Jump***	***Triple Broad Jump***
Maximal Sprinting Velocity	*Group*	0.18	-0.70	0.47	0.80	0.79	0.78
	Slow	-0.04	-0.69	0.58	0.84	0.79	0.80
	Fast	0.03	-0.21	0.23	0.60	0.28	0.39
Stride Rate	*Group*	-0.62	-0.75	0.60	0.69	0.34	0.37
	Slow	-0.46	-0.51	0.60	0.59	0.26	0.33
	Fast	-0.73	-0.85	0.52	0.55	-0.30	-0.20
Stride Length	*Group*	0.46	0.02	-0.24	0.19	0.51	0.41
	Slow	0.66	0.03	-0.33	0.14	0.50	0.41
	Fast	0.52	0.60	-0.38	-0.14	0.25	0.15
Relative Stride Length	*Group*	-0.21	-0.42	0.10	0.49	0.52	0.46
	Slow	0.20	-0.20	-0.09	0.37	0.55	0.48
	Fast	-0.42	-0.19	0.02	0.20	-0.10	-0.09
Ground Contact Time	*Group*	0.45	0.73	-0.54	-0.72	-0.46	-0.48
	Slow	0.27	0.56	-0.60	-0.69	-0.37	-0.42
	Fast	0.66	0.74	-0.37	-0.49	-0.30	0.22
Flight Time	*Group*	0.34	0.12	-0.18	-0.05	0.16	0.11
	Slow	0.32	-0.08	-0.03	0.13	0.16	0.13
	Fast	0.43	0.54	-0.41	-0.35	0.16	0.07

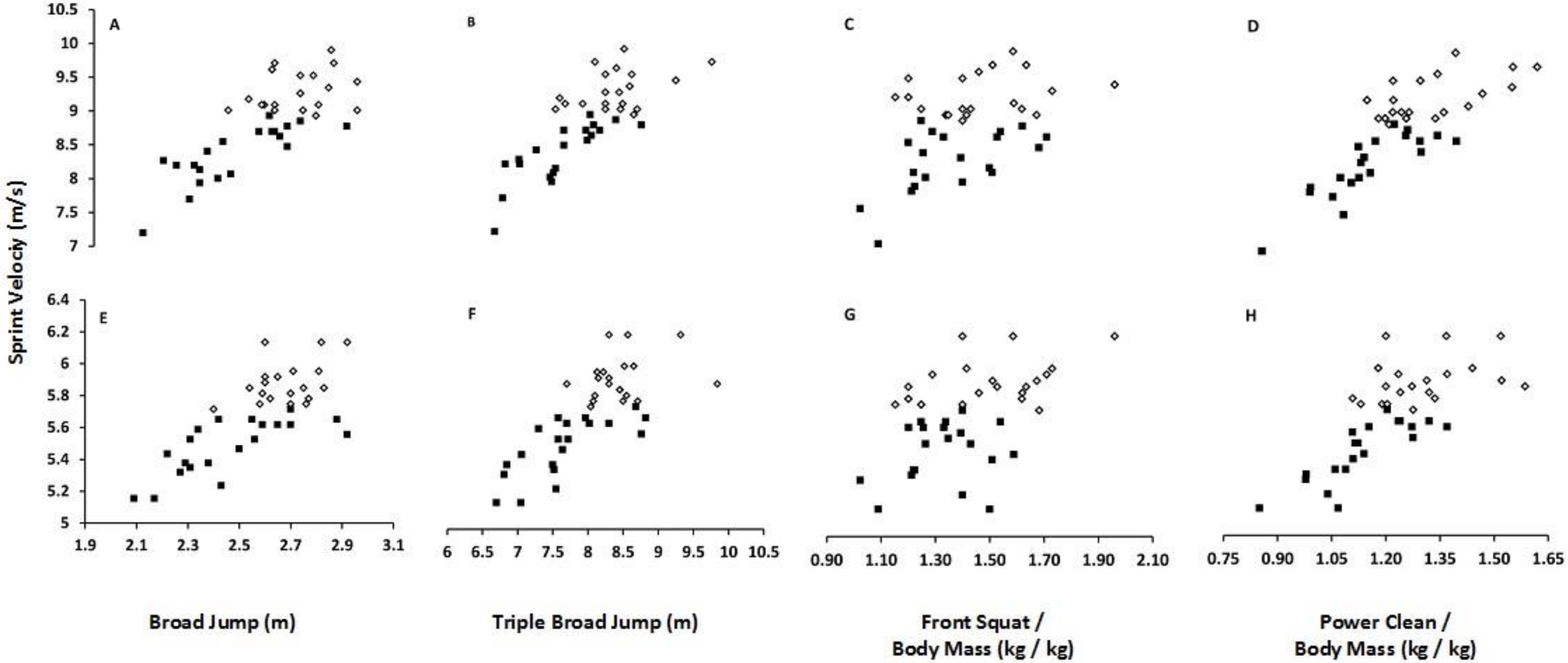

Figure 12: Scatterplots illustrating the relationships between Maximal Sprinting Velocity (A-D) and Initial Sprinting Velocity (E-H) with Broad Jump (A,E), Triple Broad Jump (B,F), Front Squat relative to body mass (C,G), and Power Clean relative to body mass (D,H). Slow Group in each of the graphs is denoted by solid black squares and the Fast Group in each graph is denoted by open diamonds.

Table 20: Changes in sprinting kinematics and different strength qualities over 1 year in elite rugby players (n=15).

Test	***Pre***		***Post***		***P value***	***Effect Size (d)***	***Magnitude***
Mass (kg)	100.6	± 11.3	101.8	± 12.2	0.08	0.11	Trivial
Triple Broad Jump (cm)	8.18	± 0.56	8.27	± 0.57	0.08	0.16	Trivial
Broad Jump (m)	2.55	± 0.43	2.58	± 0.42	0.11	0.06	Trivial
Power Clean (kg)	121.7	± 6.7	131.0	± 8.2	0.002	1.39	Very Large
Relative Power Clean (kg/kg)	1.22	± 0.13	1.30	± 0.15	0.008	0.60	Moderate
Front Squat (kg)	142.6	± 14.3	145.9	± 14.1	0.11	0.22	Small
Relative Front Squat (kg/kg)	1.43	± 0.20	1.45	± 0.19	0.48	0.07	Trivial
Acceleration Flight Time (s)	0.07	± 0.01	0.07	± 0.01	0.30	0.19	Trivial
Acceleration Ground Contact Time (s)	0.17	± 0.02	0.16	± 0.02	0.24	0.22	Small
Acceleration Stride Length (m)	1.22	± 0.11	1.31	± 0.09	0.003	0.81	Large
Maximal Velocity Stride Length (m)	2.05	± 0.11	2.08	± 0.11	0.40	0.23	Small
Maximal Velocity Ground Contact Time (s)	0.11	± 0.01	0.11	± 0.01	0.95	0.01	Trivial
Maximal Velocity Flight Time (s)	0.12	± 0.01	0.12	± 0.01	0.47	0.17	Trivial
Initial Sprint Velocity (m/s)	5.73	± 0.24	5.73	± 0.27	0.99	0.00	None
Maximal Sprint Velocity (m/s)	8.87	± 0.59	8.85	± 0.70	0.83	0.03	Trivial

Table 21: Pearson's correlation between changes in strength qualities and sprinting kinematics of elite rugby players (n=15) over 1 year of training.

Mass														
-0.47	Triple Broad Jump													
0.11	0.37	Broad Jump												
0.11	-0.14	-0.44	Power Clean											
-0.16	0.00	-0.46	0.96	Power Clean / Body Mass										
0.13	0.15	-0.41	0.56	0.48	Front Squat									
-0.30	0.37	-0.40	0.45	0.49	0.90	Front Squat / Body Mass								
0.10	-0.52	-0.07	0.35	0.35	-0.13	-0.19	Acceleration Flight Time							
0.23	-0.67	-0.28	0.13	0.09	-0.24	-0.37	0.56	Acceleration Ground Contact Time						
-0.17	0.09	0.37	0.13	0.13	0.23	0.31	0.28	-0.15	Acceleration Stride Length					
0.03	-0.10	-0.38	0.70	0.70	0.54	0.48	0.36	0.34	0.25	Maximal Velocity Stride Length				
0.37	0.32	0.18	0.32	0.23	0.39	0.25	-0.14	-0.28	-0.07	0.11	Maximal Velocity Ground Contact Time			
0.08	-0.36	-0.17	-0.13	-0.14	-0.25	-0.33	0.24	0.35	0.02	0.21	-0.61	Maximal Velocity Flight Time		
-0.28	0.42	0.03	0.14	0.21	0.41	0.49	0.09	-0.07	0.43	0.41	0.01	-0.10	Initial Sprint Velocity	
-0.33	0.11	-0.10	0.09	0.20	0.01	0.12	0.30	0.40	0.12	0.44	-0.43	0.24	0.69	Maximal Sprint Velocity

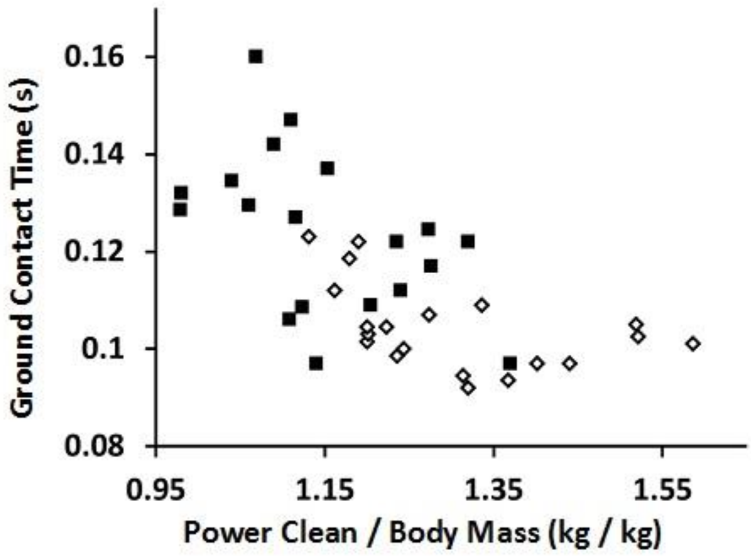

Figure 13: Scatterplot illustrating the relationship between Power Clean relative to body mass and Maximal Velocity Ground Contact Time during a 40 m sprint. Slow Group in the graph is denoted by solid black squares and the Fast Group is denoted by open diamonds.

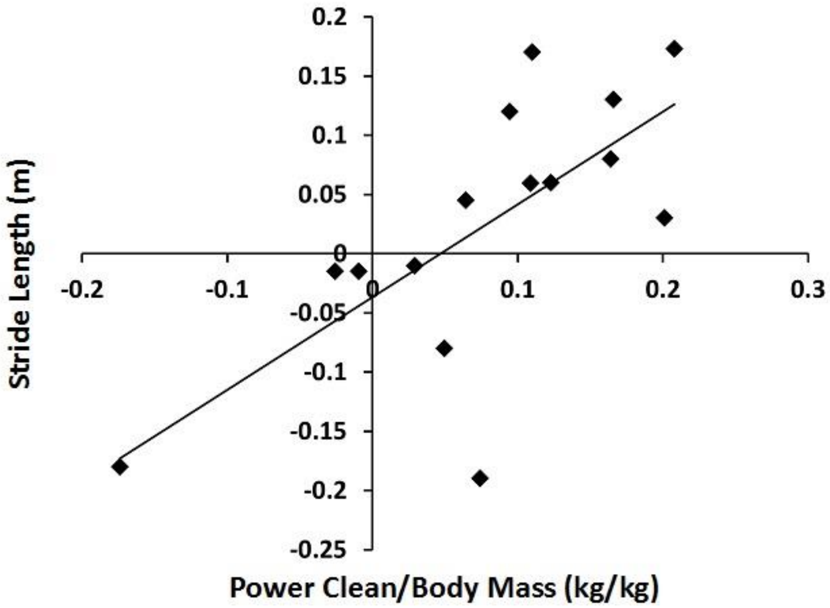

Figure 14: Correlation between changes (post score – pre score) in maximal velocity stride length and increases in power clean relative to body mass over a one year period.

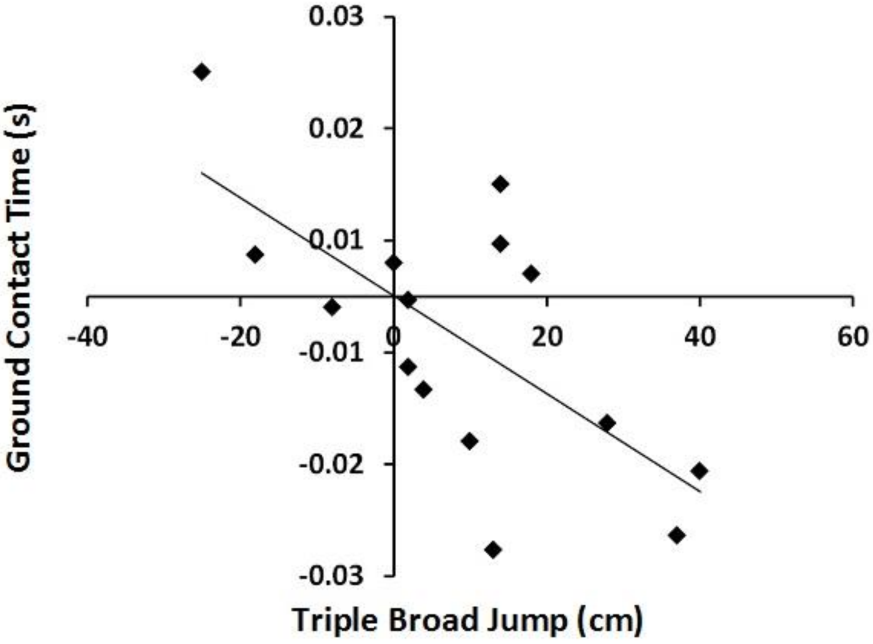

Figure 15: Correlation between changes (post score – pre score) in acceleration ground contact time and triple broad jump over a one year period.

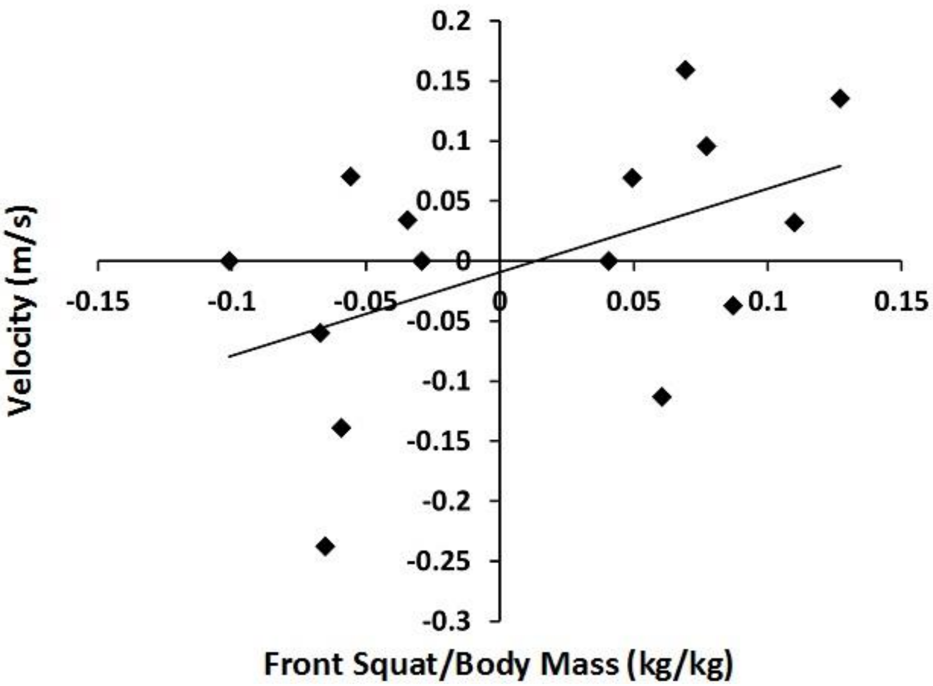

Figure 16 Correlation between changes (post score – pre score) in Initial Sprinting Velocity and Front Squat relative to body mass over a one year period.

7.5 Discussion

The results of the present study indicated that the fast groups for both acceleration and max velocity displayed better scores in the different strength qualities (Table 16 and 17). Large differences (>*d*=1.2) favouring the fast groups over the slow groups were found for PC/BM, TBJ and BJ (Table 16 and 17). FS/BM did not seem to be as good as a discriminator with only a small difference between the maximal velocity groups (*d*=0.5) and a moderate difference (*d*=0.8) in the acceleration groups. This is consistent with the results of Hori et al. (Hori et al., 2008) who found that a group of athletes with relatively high PC/BM scores were faster over 10 m than a group who had relatively lower PC/BM scores. Peak power and velocity in jump squats (Hansen et al., 2011) and horizontal jumps, drop jumps and back squat relative to body mass (Lockie et al., 2011) have also previously differentiated fast groups from slow groups over 10 m.

Given the importance of low ground contact times for high velocities during the acceleration phase of a sprint (Lockie et al., 2011), it is logical that powerful athletes who can develop force quickly (Tillin, Thomas, Pain, & Folland, 2013) will have shorter ground contact times and be faster over 10 m than their weaker peers. Ground contact time was the only sprinting kinematic measure with at least a moderate difference (0.01 s, *d*=0.8) between the Acceleration-Fast Group and the Acceleration-Slow Group which is similar to other results highlighting its importance (Hopkins, 2011; Mann, 2011). The fact that stride length showed only a small difference highlights that acceleration is dependent on developing optimal impulse and an optimal force vector (Kugler & Janshen, 2010; Lockie et al., 2013). Maximal sprinting velocity on the other

hand has been shown to be dependent on developing the necessary vertical forces while minimizing ground contact time (Weyand et al., 2010). The results of this study supported this with a very large difference (0.02 s, *d*=2.1) in ground contact time between the Maximal Velocity-Fast Group and Maximal Velocity-Slow Group. There was a moderate and large difference between stride length (0.07 m, *d*=0.8) and relative stride length (0.05 m/m, *d*=1.3) between the Maximal Velocity-Fast Group and Maximal Velocity-Slow Group which underscores the importance of stride length as the second most important kinematic factor after ground contact time.

An interesting observation in Part 1 of this study was that there were weaker correlations between maximal sprinting velocity and the strength quality tests for Maximal Velocity-Fast Group when compared to Maximal Velocity-Slow Group (Table 19, Figure 12). The correlations between Initial Sprinting Velocity with BJ, TBJ, PC/BM and FS/BM, however, were generally the same for the Acceleration-Fast Group and Acceleration-Slow Group (Table 18, Figure 12). These differences could possibly be explained by ground contact time during the different phases of sprinting. The acceleration ground contact time of both the Acceleration-Fast Group and Acceleration-Slow Group is similar at 0.16 s and 0.17 s. The maximal velocity ground contact times for the Maximal Velocity-Fast Group and Maximal Velocity-Slow Group, on the other hand were much shorter at 0.12 s and 0.10 s. The time to develop force may be the limiting factor for the potential of strength and power exercises to improve sprinting speed. For instance, PC/BM had similar associations with ground contact times for both the Acceleration-Slow Group (r=-0.61) and Acceleration-Fast Group (r=-0.56) (Table 4). However, PC/BM had a much weaker relationship with ground contact

time for the Maximal Velocity-Fast Group (r=-0.37) when compared with Maximal Velocity Slow-Group (r=-0.60) (Figure 2, Table 5). This implies that the specificity of an exercise and its potential to improve sprinting speed may be different between fast and slow athletes because of differences in ground contact time. Selecting exercises that help increase the rate of force development in less than 0.10 s may be highly important for improving maximal sprinting velocity in players that are already capable of achieving high sprinting speeds (Young et al., 1995).

Despite taking part in strength training activities year round, the average improvements of lower body strength qualities of the athletes in Part 2 of this study were generally low (Table 20). This is similar to other previously reported data that showed no improvements over the course of a year in the development of leg strength in professional rugby players (Appleby et al., 2012). The extensive strength training background, heavy competition schedules and short term injury layoffs likely contributed to this. The exception to this was PC which showed a large average improvement (121 kg to 131 kg, P=0.002, *d*=0.55) in the group (Table 20). Several of the athletes did make large improvements in all of the different tests while others actually showed decreases which resulted in the trivial mean improvement of the group as a whole.

The cross sectional data from Part 1 suggests that increasing all of the different strength qualities would increase sprinting speed and this would most likely happen by decreasing ground contact times. Interestingly, the correlation between changes in PC/BM over 1 year and changes in ground contact time during acceleration (r=0.09) and maximal velocity (r=0.23) sprinting were low and in the opposite direction of what

was expected. Changes in maximal velocity stride length on the other hand, had a very large relationship with the change in PC/BM (r=0.70). Unexpectedly, changes in PC/BM (r=0.20), FS/BM (r=0.12), BJ (r=-0.10) and TBJ (r=0.11) all had small or trivial relationships with the changes in MSV. Changes in FS/BM did have a moderate relationship (r=0.49) with the change in ISV though. These relationships highlight the problematic nature of using cross-sectional correlations to predict the effectiveness of training exercises for improving performance. The separate analyses of faster and slower groups, combined with the longitudinal analysis of the present study, further demonstrate the importance of recognising the athletes with different training ages likely have different adaptation potential to specific strength training stimuli. The physiological qualities that underpin success in sprinting and strength and power training may be similar but with reduced or even minimal remaining trainability or transfer potential in elite athletes with extensive training backgrounds. Strength and power training in athletes with minimal strength training background should improve neural drive to agonist muscles, improve stretch reflexes and intra-muscular co-ordination (Ross et al., 2001; Semmler & Enoka, 2000). This would likely improve sprinting performance by decreasing ground contact time (Rimmer & Sleivert, 2000) through an increased rate of force development (Burgess, Connick, Graham-Smith, & Pearson, 2007; Wilson et al., 1996). However the principle of diminishing returns may mean that this strategy is no longer effective in highly trained athletes.

The fact that only two athletes were able to decrease maximal velocity ground contact time over an entire year (both -0.01s) may explained by the following possibilities. The high training load and fatigue from competitions and rugby practices

may have prevented any positive adaptations to the speed and power training for many of the athletes. The exercises selected for speed and strength training (Table 15) sessions may also have been inadequate for improving sprinting speed in these players. Another possibility is that there is a limitation on the ability to develop force at high velocities. Fascicle length of hamstring muscles has previously been shown to discriminate between different levels of sprinters (Kumagai et al., 2000). The force-velocity relationship of these key sprinting muscles (R. H. Miller et al., 2012) likely has a structural limit of how much it can be improved and this probably affects the potential for strength and power training to impact maximal velocity sprinting performance. It may be the case that fascicle lengths of hamstring muscles dictate the velocity at which hip extension in sprinting can happen but greater force can be developed at that velocity through training and this allows for an improved stride length at maximal velocity. Increases in PC/BM (r=0.70) and FS/BM (r=0.48) both indeed did seem to predict changes in maximal velocity stride length.

Interestingly, there was a moderate relationship between the changes of acceleration ground contact time and TBJ (r=-0.67). Successful acceleration ability has typically been described by optimizing force vectors (Kugler & Janshen, 2010; Lockie et al., 2013) through a forward lean. It then follows that improvement in TBJ which combines an emphasis on brief contact times while jumping with a forward lean would be associated with improvements in acceleration ground contact time. Even though the associations between changes in acceleration stride length and each of the strength quality tests were all weak, the high transfer of training effect (1.33) calculated between PC/BM and acceleration stride length indicated that improving

concentric lower body explosive strength is beneficial for improving stride length during the first few steps from a standing start.

The frequent sprints that take place during rugby games mean that acceleration is likely an important physical ability for all players (Duthie, Pyne, Marsh, et al., 2006; Duthie, 2006). In highly trained rugby players, continuing to train lower body explosive strength and combining it with exercises to learn to optimize the resultant force vector such as horizontal jumps and sled sprints (Harrison & Bourke, 2009) is probably key for developing acceleration ability. It is unlikely that athletes with extensive strength training backgrounds will find that strength and power training results in improvements in maximal sprinting velocity through a decrease in ground contact time but possibly through an increase in stride length. Improving lower body maximal and explosive strength may improve acceleration ability through an increase in stride length. It is important to realize that cross-sectional correlations may highlight some shared physiological qualities between strength and power exercises and sprinting ability but these qualities may no longer be trainable in a manner that leads to transfer. It may be possible that rugby players with limited time for strength and conditioning activities are "strong enough" for their position. For instance, a winger, whose position depends on high levels of sprinting speed may have adequate lower body strength (ie power clean of 150% of body mass) to sprint at very high velocities, tackle, ruck etc. Their training time may need to be devoted to trying to increase sprinting speed through extra speed sessions and perform only a maintenance level frequency of strength training sessions. A prop, on the other hand, may need to continue to focus much of their efforts on increasing strength because scrummaging is

critical for their position and maximal strength (Quarrie & Wilson, 2000) is critical for scrummaging. Simple field tests like the ones used in the present study or more complex tests that use force plates such as mid-thigh isometric pulls, drop jumps and countermovement jumps can be utilised to gain a more complete physical profile of athletes. These tests can then be used to individualise exercise selection when designing strength training programs. Exercise selection is paramount for strength and conditioning coaches working with elite rugby players given the small possibility for further training adaptation (Baker, 2013) as well as the limited amount of strength and conditioning sessions possible due to competition schedules (Appleby et al., 2012) and injuries (Delecluse et al., 1995) that interrupt training. It would be beneficial for future research to explore how the sequencing of exercises in training and the arrangement of training sessions during the week affect physical development.

7.6 Practical Applications

Although the majority of athletes can experience improvements in sprinting ability through improving general maximal strength, the results of the current study suggest that the notion of improving maximal sprinting speed of highly trained rugby players through increasing strength is more complex. Cross-sectional data indicates that increasing strength should lead to a decrease in maximal velocity ground contact time and subsequent increases in maximal sprinting speed. The results of this study would indicate that it is difficult to decrease ground contact time in highly trained athletes and improving strength corresponds to an increase in maximal velocity stride length rather than a decrease in ground contact time. Improving different strength qualities such as concentric explosive strength and reactive strength do seem to

correspond to an improvement in stride length and ground contact during the first steps of a sprint from a standing start. Achieving high levels of maximal, explosive and reactive strength is important for elite rugby players, even if it does not result in direct transfer to sprinting speed of players with an extensive training background. It is likely rugby players with an extensive training history will reach a point of diminishing returns where their lower body strength is high enough to sprint at high velocities. If improving sprinting speed is the goal of rugby players who already possess substantial lower body strength, their training focus may need to shift from improving general strength qualities to maintaining their current strength level so that their training can have a greater focus on speed training.

Chapter 8

The Effect of 8 Days of a Hypergravity Condition on the Sprinting Speed and Lower Body Power of Elite Rugby Players

Barr, Matthew J., Sheppard, Jeremy M., Gabbett, Tim and Newton, Robert U., The effect of 8 days of a hypergravity condition for improving the sprinting speed and lower body power of elite rugby players, *Journal of Strength and Conditioning Research*, In Press.

8.1 Abstract

Sprinting speed and lower body power are considered to be key physical abilities for rugby players. A method of improving the lower body power of athletes is simulated hypergravity. This method involves wearing a weighted vest at all times during the day for an extended period of time. There are no studies that have examined the effect of hypergravity on speed or the benefit for rugby players. An experimental group (n=8) and control group (n=7) of national team rugby players took part in the study which consisted of rugby, conditioning, speed and strength sessions. The experimental group wore a weighted vest equating to 12% of their body mass for 8 days. All players were tested for speed and lower body power prior to, 2 days after and 9 days after the intervention. Speed testing involved the athletes completing 40 m sprints with timing lights and high speed video cameras assessing acceleration and maximal velocity sprinting kinematics. Lower body power was assessed using weighted countermovement jumps (CMJ). No group differences were found for sprinting speed at any point. The experimental group displayed a large decrease in acceleration ground contact time (-0.01 ± 0.005s, d=1.07) and a moderate increase in 15 kg CMJ velocity (0.07 ± 0.11 m/s, d=0.71). Individual responses showed that players in the experimental group had both negative and positive speed and power responses to the training intervention. Simulated hypergravity for 8 days is likely ineffective at improving sprinting speed while undergoing standard rugby training.

8.2 Introduction

Sprinting speed is considered to be a key physical ability for rugby players (Duthie, Pyne, Marsh, et al., 2006). Improving the sprinting speed of highly trained rugby players is difficult as players typically see a plateau in their speed after several years of training (Barr, Sheppard, Gabbett, & Newton, 2014). Improving the speed and power performance of athletes with an extensive training background is a common challenge facing coaches and scientists working with elite athletes (Issurin, 2008). Traditional methods for improving performance usually reach a point of diminishing returns where eliciting further training adaptations is no longer possible. Training to improve speed and power in athletes is typically viewed as a series of specific acute training stresses followed by a recovery period and then further training stresses (Zatsiorsky & Kraemer, 2006). The summation of these training sessions eventually results in a desired change of performance. An effective method of improving speed is the implementation of a non-specific chronic stress to produce an adaptation. Simulated hypergravity, where athletes constantly wear weighted vests to artificially “increase” the effects of gravity acting upon their body, has been shown to produce changes in lower body power in highly trained track and field athletes (Bosco, 1985; Bosco et al., 1984, 1986; Sands et al., 1996). This concept of a constant long term environmental stress to produce a desired speed and power training effect is analogous to altitude training that endurance athletes frequently undertake (Lancaster & Smart, 2012). This concept was pioneered by Bosco and colleagues (Bosco, 1985; Bosco et al., 1984, 1986) and they found that track and field athletes who wore weighted vests between 8% and 12% of body mass for three weeks were able to dramatically increase their

vertical jump despite an extensive training background and a long term plateau in performance (Bosco, 1985).

One limitation of previous hypergravity studies is that none have investigated changes in sprinting speed. It is logical to assume that an increase in lower body power would lead to an increase in speed as training studies that have shown an increase in speed also have shown an increase in lower body power (Cormie et al., 2010). If it was possible to improve sprinting speed after this type of intervention, this could be very valuable for many athletes. Sprinting speed is an important characteristic for rugby (Austin et al., 2011b; Duthie, Pyne, Marsh, et al., 2006) as well as many other team sports, so any method that would improve this quality would be highly valued by athletes and coaches. Previous hypergravity studies also reported increases in lower body power against large external loads (Bosco, 1985; Bosco et al., 1984, 1986) which would be beneficial for rugby players who experience large amounts of contact with other players.

A potential problem with this method is that wearing a weighted vest for three weeks is logistically prohibitive for team sport athletes, like rugby, who typically play games on a weekly basis. The rationale for a three week intervention was never explained in the original investigations so it is possible that a shorter time period could be effective for producing changes. Despite being a highly effective training method, the neuromuscular changes that might drive changes in performance have also been unstudied so the time course of adaptation is difficult to predict. The only study that measured changes in vertical jump performance on a weekly basis noted a positive adaptation in the experimental group somewhere between the 1st and 2nd week after

wearing the vest (Sands et al., 1996). It is possible that wearing the vest for a time period less than three weeks is enough to improve performance. Bye-weeks are common in rugby and other team sports so if a shorter term hypergravity intervention was effective, it could be used occasionally by team sport athletes for around a one week period. Elite rugby players spend much of their year in competition periods and dedicated physical training periods are infrequent (Appleby et al., 2012) so it would be desirable if short-term effective training methods could be regularly introduced to improve performance.

With this in mind, the purpose of the current study was to examine if short term simulated hypergravity was effective at producing changes in the sprinting speed and lower body power of elite rugby players. Pilot data (Figure 17) that we collected on two international rugby players with extensive sprint training background showed substantial improvements in acceleration ability after a week of simulated hypergravity so it was hypothesized that the players in the current study would be able to make similar improvements in sprinting speed and lower body power. It was also expected that the increased sprinting speed would occur through a decrease in ground contact time.

8.3 Methods

8.3.1 - Experimental Approach to the Problem

In order to assess the effect of simulated hypergravity on improving sprinting speed and lower body power, the players were tested for sprinting speed and weighted jumps the day before the 8 day intervention, two days after the intervention ended

and nine days after the intervention (Table 22). The experimental group wore a weighted vest (Perform Better, Cranston, RI) equal to 12% of body mass for 8 days. The rationale for the weighted vest of 12% of body mass was based on the similar weight of vests used during previous studies. Eight days was chosen as the time frame of the intervention because pilot data with two international wingers showed sharp improvements in sprinting speed over the first 10 m of a sprint (Figure 17) after wearing a weighted vest (12% of body mass) for this time period.

8.3.2 - Subjects

In order to assess the potential benefit of simulated hypergravity, 17 players from a training squad of a national team academy were recruited to participate. Two players participating in the study were removed due to injuries (shoulder and concussion) sustained during rugby practices leaving 15 players between the experimental (n=8, mass=95.3 ± 7.1 kg, height=1.82 ± 0.06 m, age=22.4 ± 2.7 years) and control groups (n=7, mass=92.8 ± 11.4 kg, height=1.86 ± 0.07 m, age=22.0 ± 2.1 years). All participants gave informed written consent to take part in the study which had Institutional Review Board approval.

8.3.3 - Speed and Jump Testing

During the testing sessions, each of the players performed four 40 m sprints on an artificial grass field using an electronic timing system (Brower, Draper, USA) with timing gates placed upon 1 m high tripods at 0 m, 10 m, 30 m and 40 m. The players began each sprint with their front foot beside a cone 0.75 m behind the first gate. The 0-10 m split was used to assess acceleration ability and the 30-40 m split was used to

assess maximal velocity sprinting ability, as highly trained rugby players reach their maximal velocity between 30 and 40 m (Barr et al., 2013; Higham et al., 2013). Prior to the testing period, the participants undertook a 25 minute warm up that included light running, dynamic stretches and three 40 m sprints that progressively increased in intensity from 60% of maximal volitional effort to 95% of maximal effort. After warm-up, the participants were given a four minute break before they performed their first 40 m sprint and four to five minutes of passive rest after each subsequent sprint. The 40 m sprint with the fastest time and the corresponding splits were kept for later analysis.

In order to characterize sprinting kinematics, each of the sprints were filmed using two Nikon J1 (Nikon, Tokyo, Japan) video cameras recording at 400 frames per second. Calibration markers were placed 0.5 m to either side of the run at 0 m, 6 m, 30 m and 36 m. A camera recorded each of the sprints for the 0-6 m section and the other camera recorded the 30-36 m section. In order to assess the sprinting kinematics of each player, stride rate, stride length, relative stride length, ground contact time and flight time were calculated with the aid of computer software (Kinovea). A stride was considered to be the time from touchdown of one leg to the last instant before touchdown of the other leg. Stride length was determined by measuring the distance between successive toe-off positions in each stride, with the most anterior part of the foot at toe off used as a marker for measuring stride length. Ground contact times were calculated by counting the number of frames (0.0025 s per frame) between touchdown and toe-off. Flight time was determined by counting the number of frames between toe-off and touchdown. Stride rate was determined by dividing one stride by

the time taken to complete it (1/ground contact time + flight time). The average of the first three strides was used for the 0-6 m section and two strides for the 30-36 m section. Pilot data was analyzed by two individuals with experience analyzing sprinting technique in order to determine inter-rate reliability of this method. Typical error of measurement (TEM) and Intraclass Correlations (ICC) were calculated from video analyzed by both testers. Strong inter-rater reliability for these kinematic assessment methods were found for stride length (ICC=0.99, TEM=0.017 m), ground contact time (ICC=0.95, TEM=0.005 s), and flight time (ICC=0.84, TEM=0.003 s).

In order to assess lower body explosive strength, a weighted countermovement jumping test with external loads of a barbell and plates weighing 15 kg, 40 kg and 70 kg were used. The athletes involved in the study performed three jumps at each of the weights with 5 s between jumps and 5 minutes between each of the sets with the sets done in ascending order (15 kg, 40 kg, 70 kg) on all of the testing days. If the athletes lost balance or had a less than maximal effort jump, the jump was discarded and one more attempt was given. Peak velocity in each jump was recorded with a Tendo Power and Speed Analyzer (Tendo Sport Machines, Trencin, Slovak Republic) attached to the end of a barbell. The scores of both Tendo units were recorded for each jump and averaged to give the score for each jump. The highest velocity of the three jumps was used in the statistical analysis.

8.3.4 - Training

The training in the study consisted of rugby practices, speed training and strength training sessions (Table 22) during pre-season training. Rugby training during the study involved practices focusing on technical passing, catching and kicking drills as well as

different conditioning games that varied in numbers per team (4 to 7), contact (touch rugby or full tackle/rucks) and space (full field or half field). Speed training sessions during the study involved approximately 200 m of sprinting volume per session and were focused on acceleration ability with the players performing sprints ranging from 10 m to 25 m sprints and lightly weighted sled resisted sprints (D. West et al., 2013) up to 10 m in length. Strength training sessions during the program were individualized for each player but in general, consisted of 5-6 sets of snatch or clean and jerk variations (2-4 reps), 5-6 sets of squats or jump squats (4-6 reps), 5-6 sets of upper body pressing and pulling exercises (5-8 reps), training for the abdominal muscles and some individualized injury prevention work for the hamstrings, rotator cuff, ankles or neck. The only difference between the experimental group and the control group was that the experimental group wore a weighted vest (Perform Better, Cranston, RI, USA) that was adjusted to 12% of their body mass. The participants in the experimental group were instructed to wear the vest at all times during the day in which they were standing or walking with the exception of rugby practices and showering. During strength training sessions the participants would remove the vest during their actual sets of lifting a barbell but would wear it during their rest intervals.

8.3.5 - Statistical Analysis

To determine if there were difference between the experimental and control groups over the course of intervention, repeated measures ANOVAs with Tukey's post-hoc analyses were used. Significance was set at $P \leq 0.05$. In order to understand the magnitude of changes over the course of the study, Cohen's *d* effect sizes were calculated. The following classification system was used to determine the magnitude

of Cohen's *d* effect sizes. Effect sizes of <0.2, 0.2 to <0.49, 0.5 to <1.0, and ≥1.0 were considered trivial, small, moderate, and large, respectively.

An analysis of individual responses was performed by determining the smallest worthwhile difference for each of the measurements and then counting the number of individuals where the change in performance was greater or less than this amount. The smallest worthwhile difference was determined as one fifth of the pre-testing standard deviation (Hopkins, 2011). This equates to a Cohen's *d* effect size change of 0.2. If the Typical Error of Measurement calculated from pilot data was found to be greater than 0.2 for a variable, then it was used as the smallest worthwhile difference. All statistical analysis was performed using Microsoft Excel (Microsoft Excel, Seattle, USA) and XLSTAT (Addinsoft, New York, NY, USA).

8.4 - Results

Reliability for each of the measurements was calculated with intraclass correlations (ICC) and Typical Error of Measurement (TEM). For the sprinting measurements, strong reliability was found for the 0-10m time (ICC=0.87, TEM=0.02 s), 30-40m time (ICC=0.98, TEM=0.02 s), 40 m time (ICC=0.9, TEM=0.03 s), Acceleration GCT (ICC=0.75, TEM=0.005 s), Acceleration FT (ICC=0.75, TEM=0.006 s), Acceleration SL (ICC=0.85, TEM=0.026 m), Maximal Velocity GCT (ICC=0.8, TEM=0.003 s), Maximal Velocity FT (ICC=0.82, TEM=0.007 s) and Maximal Velocity SL (ICC=0.7, TEM=0.05 m). For the jumping measurements, strong reliability was found for the 15 kg, (ICC=0.84, TEM=0.06 m/s), 40 kg (ICC=0.72, TEM=0.08 m/s) and 70 kg (ICC=0.75, TEM=0.08 m/s) countermovement jumps.

Differences in acceleration ground contact between the experimental and control groups were detected at the Post 2 testing (P=0.006) and for maximal velocity at the Post 1 testing (P=0.03). No other differences between groups were detected at any other points. A large reduction in ground contact time (-0.01, *d*=1.06) from the pre-testing to the Post 2 testing was observed in the experimental group. Moderate changes in 15 kg countermovement jump peak velocity were shown for the experimental group from pre-testing to Post 2 (0.07 m/s, *d*=0.71). Individual responses showed mostly neutral responses for the control groups with only two positive responses across the tests of speed and jumping ability (Table 25). On the other hand, the experimental group had at least one positive responder in each of the speed and jumping tests with five individuals positively responding to the 15 kg jump (Table 25 and Figure 17). The individual responses to the 40 m sprint time showed no negative or positive responses in the control group but 4 negative and 2 positive responses in the experimental group (Table 25 and Figure 18).

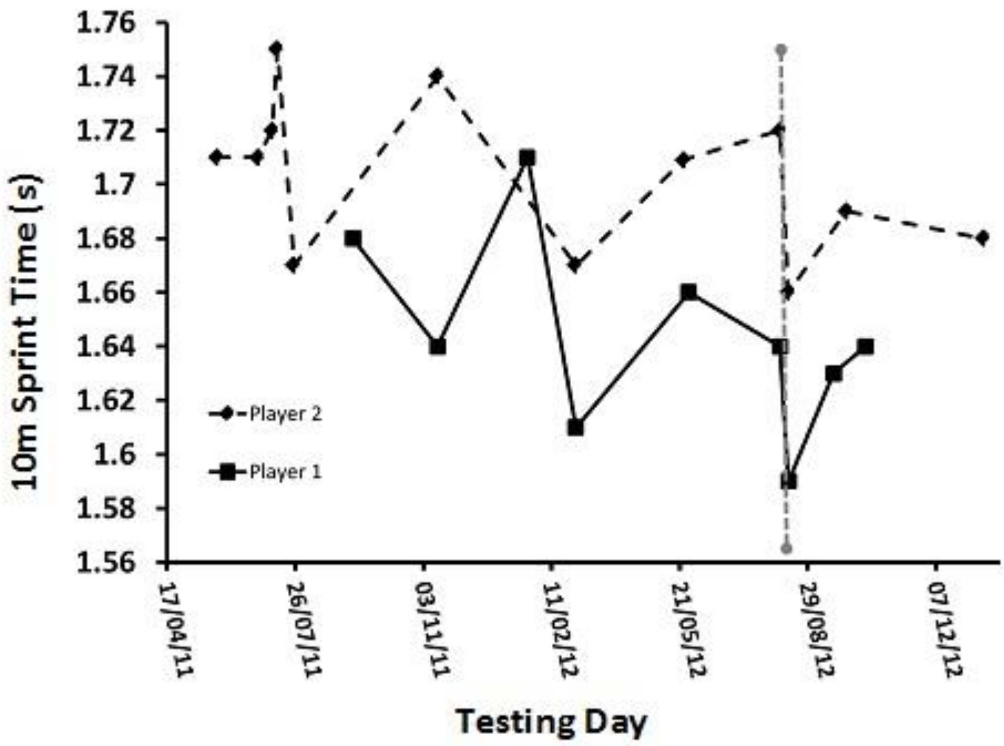

Figure 17: Pilot data showing changes in sprint time over 10 m for two international rugby union wingers over approximately one and a half years of training. The dashed vertical line indicates when the players began wearing a weighted vest (12% of bodymass) for an eight day period. Both players experienced a large short term increase in their acceleration ability.

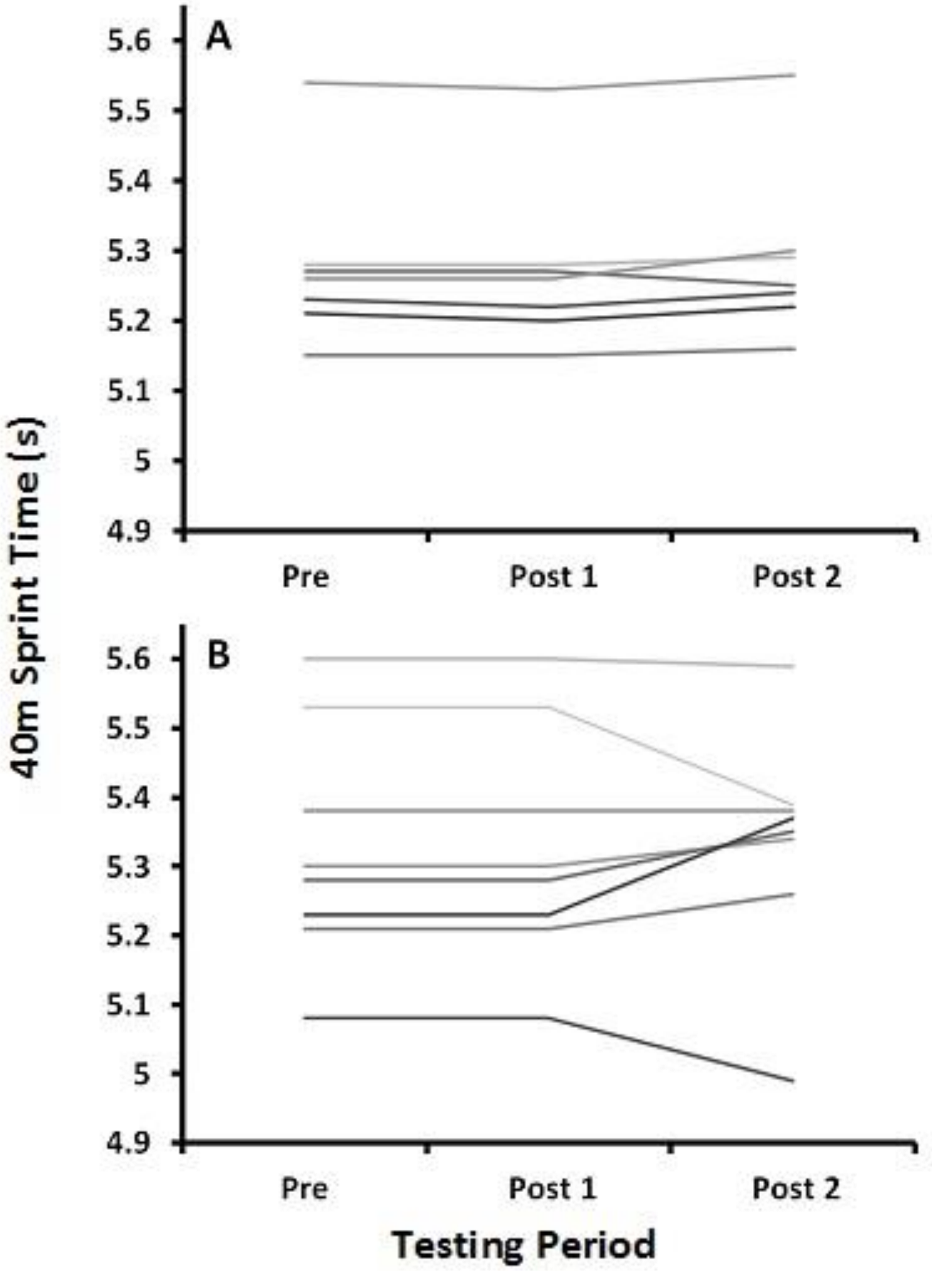

Figure 18: Changes in 40 m sprint times prior to (Pre), two days after (Post 1) and nine days (Post 2) after the weighted vest intervention. Control group (n=7) is displayed in top graph (A) and experimental group (n=8) is displayed in the lower graph (B).

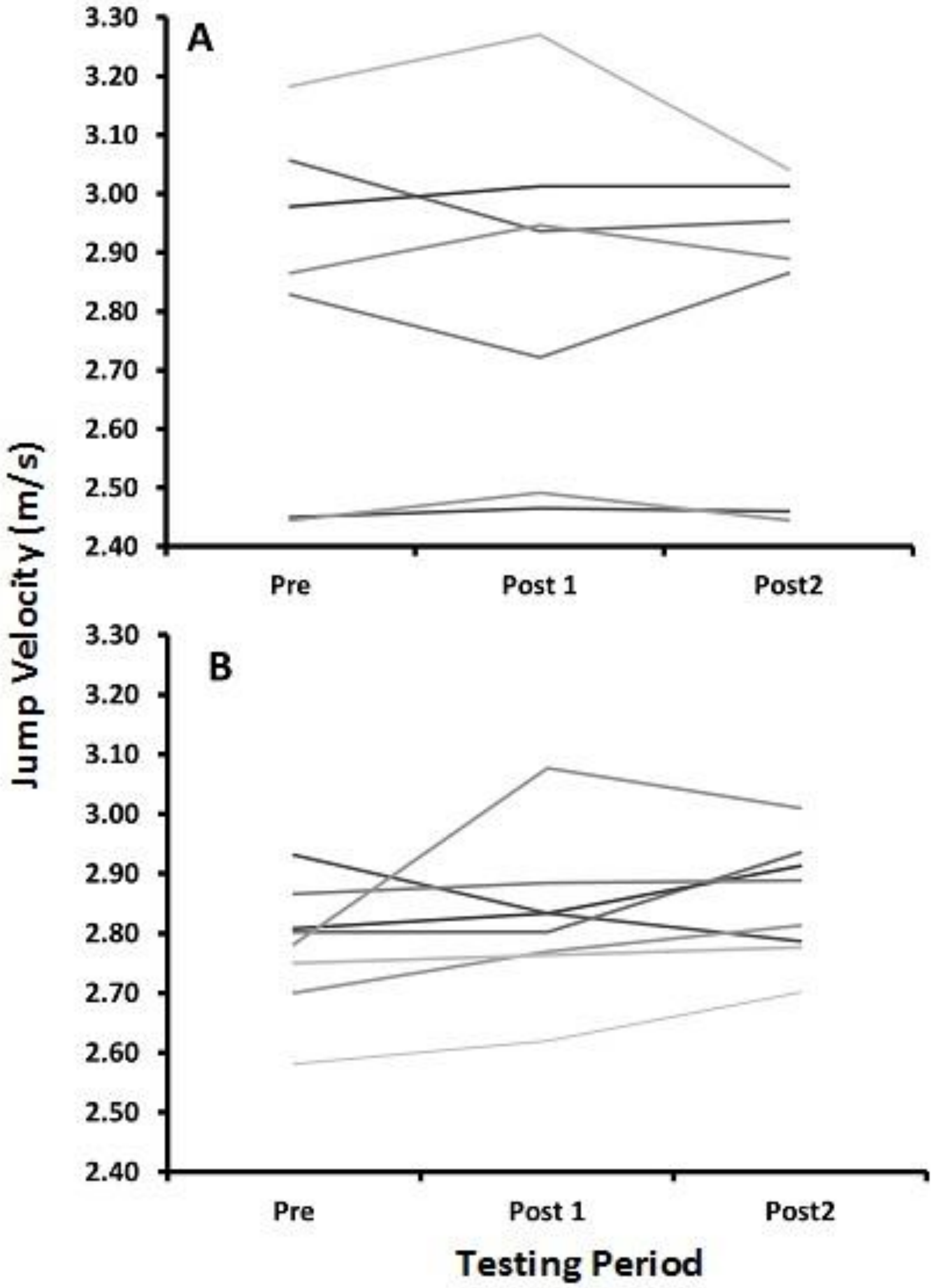

Figure 19: Changes in peak velocity during a 15 kg weighted countermovement jump prior to (Pre), two days after (Post 1) and nine days (Post 2) after the weighted vest intervention. Control group (n=7) is displayed in top graph (A) and experimental group (n=8) is displayed in the lower graph (B).

Table 22: The training plan during the experimental period outlining rugby, speed, weights and conditioning sessions. The days in grey indicate when the players in the experimental group wore a weighted vest equal to 12% of body mass.

Week	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
1			BREAK		*Afternoon* Testing *Evening* Skills Training	*Morning* Skills Training *Afternoon* Skills Training *Evening* Conditioning Games	*Morning* Skills Training
2	*Afternoon* Skills and Conditioning Games	*Morning* Weights *Afternoon* Skills	Rest Day	*Morning* Speed Weights *Afternoon* Conditioning Games	*Morning* Weights *Afternoon* Skills and Conditioning Games	Rest Day	Rest Day
3	*Morning* Testing Weights	*Morning* Weights Skills and Conditioning Games	Rest Day	*Morning* Speed Weights Skills Training	*Morning* Weights	*Morning* Skills and Conditioning Games	Rest Day
4	*Morning* Testing						

Table 23: Changes in sprinting performance and sprinting kinematics prior to (Pre), two days after (Post 1) and nine days (Post 2) after the weighted vest intervention. Effect sizes and magnitude of difference are reported for each change. A repeated measure ANOVA with a Tukey's Post Hoc analysis was used to identify differences between the groups at each of the time periods. Acc = acceleration. Max V = maximal velocity. GCT = ground contact time. SL = stride length. FT = flight time.

		Pre		**Post 1**		**Post 2**		**Change**		**Between Group Differences**
		x̄	*s*	x̄	*s*	x̄	*s*	Pre to Post 1	Pre to Post 2	
0-10 m Time (s)	Control	1.76	*0.07*	1.76	*0.07*	1.78	*0.08*	0.0, d=0.0, none	0.02, d=0.11, trivial	No significant differences
	Experimental	1.76	*0.07*	1.76	*0.07*	1.78	*0.08*	0.0, d=0.0, none	0.02, d=0.28, small	
30-40 m Time (s)	Control	1.12	*0.02*	1.12	*0.02*	1.12	*0.02*	0.0, d=0.0, none	0.0, d=0.19, trivial	No significant differences
	Experimental	1.12	*0.05*	1.12	*0.05*	1.14	*0.04*	0.02, d=0.0, trivial	0.02, d=0.27, small	
40 m Time (s)	Control	5.28	*0.12*	5.27	*0.12*	5.29	*0.12*	-0.01, d=0.03, trivial	0.01, d=0.08, none	No significant differences
	Experimental	5.33	*0.17*	5.33	*0.17*	5.33	*0.17*	0.0, d=0.17, trivial	0.0, d=0.04, none	
Acc GCT (s)	Control	0.17	*0.01*	0.17	*0.01*	0.17	*0.01*	0.0, d=0.18, trivial	0.0, d=0.05, none	Post 2, P=0.006
	Experimental	0.16	*0.01*	0.16	*0.01*	0.15	*0.01*	0.00, d=0.28, small	-0.01, d=1.06, large	
Acc FT (s)	Control	0.07	*0.01*	0.07	*0.01*	0.07	*0.01*	0.0, d=0.14, trivial	0.0, d=0.09, trivial	No significant differences
	Experimental	0.07	*0.01*	0.07	*0.01*	0.07	*0.01*	0.0, d=0.25, small	0.0, d=0.10, trivial	
Acc SL (m)	Control	1.33	*0.07*	1.35	*0.07*	1.34	*0.06*	0.02, d=0.18, trivial	0.01, d=0.02, trivial	No significant differences
	Experimental	1.25	*0.09*	1.26	*0.10*	1.24	*0.12*	0.01, d=0.07, trivia	-0.01, d=0.15, trivial	
Max V GCT (s)	Control	0.11	*0.01*	0.11	*0.01*	0.11	*0.01*	0.0, d=0.1, trivial	0.0, d=0.22, small	Post 1, P=0.03
	Experimental	0.11	*0.01*	0.10	*0.01*	0.11	*0.01*	-0.01, d=0.09, trivial	0.0, d=0.16, trivial	
Max V SL (m)	Control	2.07	*0.09*	2.12	*0.11*	2.09	*0.11*	0.05, d=0.57, moderate	0.02, d=0.23, small	No significant differences
	Experimental	2.02	*0.15*	2.07	*0.13*	2.04	*0.13*	0.05, d=0.28, small	0.02, d=0.12, trivial	
Max V FT (s)	Control	0.11	*0.01*	0.12	*0.01*	0.11	*0.01*	0.01, d=0.54, moderate	0.0, d=0.10, trivial	No significant differences
	Experimental	0.11	*0.10*	0.12	*0.01*	0.12	*0.01*	0.01, d=0.40, small	0.01, d=0.21, small	

Table 24: Changes in peak velocity during the weighted countermovement jumps prior to (Pre), two days after (Post 1) and nine days (Post 2) after the weighted vest intervention. A repeated measures ANOVA with a Tukey's Post Hoc analysis was used to identify differences between the groups at each of the time periods.

		Pre		Post 1		Post 2		Change		Between Group Differences
		x̄	*s*	x̄	*s*	x̄	*s*	Pre to Post 1	Pre to Post 2	
15kg Jump (m/s)	Control	2.83	*0.29*	2.84	*0.29*	2.81	*0.25*	0.01, d=0.02, trivial	-0.02, d=0.07, trivial	No significant differences
	Experimental	2.78	*0.11*	2.82	*0.13*	2.85	*0.10*	0.04, d=0.43, small	0.07, d=0.71, moderate	
40kg Jump (m/s)	Control	2.52	*0.18*	2.51	*0.16*	2.52	*0.14*	-0.01, d=0.09, trivial	0.0, d=0.02, trivial	No significant differences
	Experimental	2.47	*0.12*	2.42	*0.10*	2.47	*0.11*	-0.05, d=0.42, small	0.00, d=0.11, trivial	
70kg Jump (m/s)	Control	2.16	*0.19*	2.11	*0.15*	2.13	*0.15*	-0.05, d=0.28, small	-0.03, d=0.16, trivial	No significant differences
	Experimental	2.10	*0.14*	2.04	*0.14*	2.06	*0.12*	-0.06, d=0.46, small	-0.04, d=0.29, small	

Table 25: Negative, neutral and positive responders to the training intervention as determined at nine days after the training intervention was completed. Negative and positive responders were determined by a change in performance that was greater than the Smallest Worthwhile Difference. The Smallest Worthwhile Difference was determined to be 0.2 of the pre-testing standard deviation. If the Typical Error of Measurement was greater than 0.2 of the pre-testing standard deviation, it was used as the Smallest Worthwhile Difference.

	Smallest Worthwhile Difference	Control Group			Experimental Group		
		Negative	Neutral	Positive	Negative	Neutral	Positive
0-10 m Time	0.02 s	2	4	1	3	4	1
30-40 m Time	0.02 s	0	7	0	3	4	1
40 m Time	0.03 s	0	7	0	4	2	2
15kg Jump	0.06 m/s	2	5	0	1	2	5
40kg Jump	0.08 m/s	0	6	1	0	7	1
70kg Jump	0.07 m/s	2	5	0	2	5	1

8.5 Discussion

A main hypothesis of this study was that the hypergravity intervention would lead to an improvement in sprinting speed. A comparison of the means (Table 23) would suggest that the weighted vest intervention was unsuccessful in improving sprinting speed and only moderately successful in increasing lower body power. This result was surprising given that the two athletes who wore the weighted vest in our pilot study achieved personal best sprinting times (Figure 17) over their first 10 m. The findings of Sands et al. (Sands et al., 1996) seemed to show a positive adaptation in the experimental group somewhere between the 1st and 2nd week after wearing weighted vests. None of the other studies that have examined the phenomena measured the time course of adaptation. It is possible that the two athletes in the pilot study made their improvements by chance alone. However the subjects' training during the course of the current study may have negated potentially larger hypergravity training intervention effects in the present study. During our pilot study, the two athletes were in a pre-season training phase that involved sprinting three times per week, strength training four times per week that was focused on improving sprinting speed (plyometrics, power exercises etc.) and one day per week of maintenance conditioning. This is similar to how a track and field sprinter would train, and may explain the large magnitude changes similar to that observed in previous studies (Sands et al., 1996). The athletes in the current study were in a pre-season training camp during the study that included four conditioning sessions during the eight day intervention period. These conditioning sessions may have negated any improvements that the intervention might have provided. It has previously been shown that

performing strength and endurance training concurrently negatively affects rate of force development (Häkkinen et al., 2003), high velocity strength (Glowacki et al., 2004) and jumping power (Glowacki et al., 2004). The expected adaptation from the current study was that the hypergravity intervention would lead to an increase in rate of force development which would subsequently lead to a decrease in ground contact time and an increase in flight time. The experimental group actually did show a decrease in acceleration ground contact time (0.01 s, *d*=1.07) that was significantly different from the control group at the Post 2 testing session (P=0.006). This was accompanied by a moderate improvement in the 15 kg weighted countermovement jump (0.07 m/s, *d*=0.71). These changes may suggest that the athletes were making positive adaptations but the intervention was of inadequate duration, or that the heavy conditioning work negated the positive adaptations that would've taken place. The one study (Rusko & Bosco, 1987) that examined changes in endurance athletes from hypergravity noted improved performance in runs to exhaustion but improvements in maximal sprinting speed and lower body power were not measured.

The individual responses (Table 25, Figure 18 & 19) to the training showed some interesting results. The control group had mostly neutral responses on the tests whilst the experimental group had both negative and positive responses (Table 25) to the speed and jumping tests. This would indicate that wearing the weighted vest did place a large stress on the body but the response rates were different. Four of the players had negative responses to their 40 m sprinting time while two had improvements greater than the smallest worthwhile difference. This might suggest that players actually saw a decrease in sprinting speed before a subsequent supercompensation

that increased sprinting speed to a new level. Most of the players in the experimental group were selected for their respective national 7s team for back to back tournaments on the IRB Sevens Series that took place a few weeks after the study finished. The team had their best two tournaments of the year, and so the intervention at the least did not appear to have negatively affected their on-field performance. Of course, success in rugby is multi-factorial, but it is possible that the players in the experimental group made positive improvements in speed and power after the last testing date while they were on a reduced volume of training the week before the first tournament. However, based on the data in the present study, this is only speculation. Future studies involving hyper-gravity training interventions with athletes concurrently training under high loads in other areas of performance (conditioning, skills, game-based play), should consider additional testing during low volume weeks subsequent to the training intervention, to possibly detect retention rates of responders and possibly those athletes that respond to the intervention over a longer time course.

Understanding the mechanisms of how hypergravity improves performance will help determine how to incorporate the intervention into training programs in a way that maximizes its benefit. It has been shown that having endurance runners warm up with weighted vests improves peak running speed in a running test to exhaustion by increasing joint stiffness (Barnes, Hopkins, McGuigan, & Kilding, 2014). It is possible that the same affect is true for sprinting. Walking around wearing the vest prior to training sessions may have the effect of potentiating the subsequent speed session. The early work (Bosco, 1985; Bosco et al., 1984, 1986; Sands et al., 1996) examining

hypergravity demonstrated that it can be a powerful training tool that makes large changes with athletes in a short period of time. Changes of that magnitude are unlikely to occur as quickly with any other training intervention in elite populations. Thus, this area warrants further research to determine if the weighted vests have application outside of track and field and can be used effectively for time periods less than 3 weeks. It would be worthwhile to investigate if a one week weighted vest intervention is effective with team sport athletes if it is performed with minimal or no conditioning sessions and a focus on speed and power training. It will be important for future studies to explain how simulated hypergravity results in neuromuscular changes that lead to improvements in performance.

8.6 - Practical Applications

The mean results of the current study would suggest having rugby players undergo a week of hypergravity while concurrently performing normal rugby training is ineffective at increasing speed and power. However, there were some individual responses to the intervention that demonstrate that it may have some application at increasing these physical abilities. It may be worthwhile to trial hypergravity with athletes during time periods with little conditioning work to see if they respond positively to the intervention. There may be instances where players who have very high levels of aerobic conditioning but have inadequate sprinting speed and lower body power might benefit from this intervention. If the competition schedule allows, it may be beneficial for these athletes to undergo a week of hypergravity training. It would be recommended that all aspects of the training plan be carefully considered if

the desired changes are to occur though as it is likely that heavy aerobic conditioning prevents improvement in sprinting speed and lower body power.

Chapter 9

Summary and Conclusions

9.1 Summary of Findings

Speed is unquestionably an important physical ability for rugby union players. There are many understudied areas in the field of sprint speed development particularly when compared to a field such as strength training, which has been much more extensively researched. The results of this thesis have helped contribute to our understanding of the topic in several important ways. Many of the key findings relate to developing a greater understanding of sprinting biomechanics in rugby players. Qualitatively, sprinting can be divided into an *Initial Acceleration*, *Mid-Acceleration*, *Transition to Maximal Velocity* and *Maximal Velocity* phases. One key finding was that all players in hit their maximal sprinting velocity between 30 and 40 m regardless of their peak sprinting velocity being as high as 10 m/s or as low as 8 m/s (Study 1). Speed training methodologies for rugby are often derived from track and field practices and elite sprinters on a track hit maximal velocity between 50-60 m (Gajer et al., 1999). In addition, the players were at 95% of their maximal sprinting velocity at around 21 m into a sprint. This would mean that rugby players that need to improve their *Maximal Velocity* phase don't need to sprint as far as 60 m to do this. They likely only need to perform sprints between 20 and 40 m to specifically train maximal velocity sprinting, this is an important practical recommendation from this thesis.

As players transition from a standing start to maximal velocity, they do so without an appreciable change in stride rate (4.24 – 4.4 stride/s) but with a substantial increase in stride length (1.22 m to 2.08 m). Stride rate remains the same because ground contact time and flight time are inversely proportional with each other as they move from low velocity (5.22 m/s), high ground contact time (0.174 s) and low flight time (0.061 s) to

high velocity (8.98 m/s), low ground contact time (0.113 s) and high flight time (0.118). The key sprinting kinematics (Study 5) that were found to discriminate fast players from slower players were ground contact time and stride length for both acceleration and maximal velocity. Ground contact time during maximal velocity sprinting was a particularly strong discriminator which is consistent with other research that emphasized its importance in achieving high sprinting velocities (Mann & Herman, 1985; Weyand et al., 2010) and that a positive adaptation to improving maximal sprinting velocity is its decrease (Rimmer & Sleivert, 2000).

Another important finding related to sprinting biomechanics was that sprinting with a rugby ball in one hand does not seem to negatively affect international players in either acceleration phases or maximal velocity phases (Study 2). The sprinting speed of international level players was also not negatively affected by sprinting with the ball in two hands to the same extent that was previously reported with amateur players (Grant et al., 2003; Walsh et al., 2007). There were several players who were slower sprinting with the ball in two hands when compared with a normal no-ball sprint by a margin greater than the Technical Error of Measurement. The implication of these findings is that elite players are usually better than lower level players at sprinting with a ball in two hands, but elite players should be tested for their ball carrying speed to identify potential individual weaknesses.

An important consideration for player development that we examined in Study 3 was the relationship between mass, sprinting speed and sprint momentum. The relationship of mass with initial sprinting velocity and maximal sprinting velocity showed that mass has a strong negative relationship with both of these qualities,

particularly maximal velocity (r=-0.69). This relationship is likely due to the inability of heavier players to develop the mass specific forces (Weyand et al., 2010) necessary to shorten ground contact time and produce high sprinting velocities. The relationship between maximal velocity ground contact time and body mass (r=0.67) for all 40 players studied in Study 5 would support this. Maximizing sprinting speed and sprint momentum is a trade-off though because body mass has very strong correlations with sprint momentum (r=0.84 and r=0.92). In Study 4, body mass and height were found to be higher in successful teams at the 2007 and 2011 Rugby World Cups when compared with less successful teams. Even a position such as winger, where speed is considered a highly valuable ability, will weigh as much as 105 kg (Table 14) in international rugby. The senior players examined in Study 3 were found to have much greater sprint momentum and body mass, but not sprinting speed, when compared to junior players. Collectively, all of these results point to sprint momentum as a highly important physical quality for a rugby union player. Sprinting speed is an important outcome of training programs, but sprint momentum is probably more important in the specific context of rugby. This is an important consideration, in that it means that it is likely unadvisable for a rugby player to optimize body mass solely for sprinting performance (Uth, 2005) as it would not be optimal for sprint momentum.

One of the central questions of this thesis was whether or not increasing different lower body strength qualities would result in an improvement in sprinting speed. The relationship between sprinting kinematics and lower body strength qualities was assessed in Study 5. The faster groups for both acceleration and maximal velocity showed large differences in favour of the faster group for power clean relative to body

mass, broad jump and triple broad jump but only small and moderate differences for front squat relative to body mass. This supports previous research that has shown that stronger and more powerful rugby players are faster sprinters (Baker & Nance, 1999; Cunningham et al., 2013). An important finding in Study 5 was that ground contact time, also detailed in Study 1, is key aspect for determining the specificity of exercise. The correlations between front squat, power clean, broad jump and triple broad jump with acceleration were similar for the slow group and fast groups. Conversely, these strength capabilities had much stronger correlations with maximal sprinting velocity in the slow group then the fast group. This can be explained by the longer average ground contact times for both the slow and fast group (0.17 s and 0.16 s) in acceleration and the shorter times in maximal velocity (0.12 s and 0.10 s). Average ground contact time 15 m into a sprint (*Transition to Maximal Velocity* phase) was 0.12 s so ground contact times quickly shorten as players begin accelerating as detailed in Chapter 2. Maximal strength exercises like squats may be beneficial for the first 10 m of a sprint where the contact times are longer. When selecting strength, power and plyometric exercises to improve sprinting speed, it is likely important to consider which phase of a sprint is being targeted. The specificity of an exercise and its potential to improve sprinting speed may be different between fast and slow athletes because of differences in ground contact time as well as the different phases of sprinting.

The athletes examined in Study 5 were tracked over a one year period and did not show positive improvement in sprinting speed from increasing the different strength qualities. These results suggest that there is a ceiling limit to how much strength training can improve sprinting speed. It is highly likely that all of the players in this

study benefited from an improvement in sprinting speed through increasing lower body strength early in their careers but had since passed a point where general strength training would directly transfer to an improved sprinting performance. The physiological qualities that underpin success in sprinting and strength and power training may be similar but with reduced or even minimal remaining trainability or transfer potential in elite athletes with extensive training backgrounds. However, the athletes in Study 3 were able to effectively improve their sprinting speed over a two year period and did so while spending hundreds of hours in the weight room focusing on developing strength and power. The athletes in Study 3, particularly the junior players, most likely had a higher potential for improving sprinting speed than the players in Study 5. The strength training (Olympic lifts, squats, plyometrics) that they used in their training was likely effective at improving lower body strength relative to body mass. Increasing their strength relative to body mass was important so that the players could make improvements in their sprinting speed while gaining lean body mass and subsequently improve their sprint momentum. Developing sprint momentum likely requires strength training exercises that increase both body mass and lower body power such as the Olympic lifts (Barr, 2012). Even if strength training exercises are not important for improving sprinting speed, they are undoubtedly highly important for improving sprint momentum. An increase in body mass without a subsequent increase in lower body power would likely result in a decrease in sprinting speed.

Utilizing various effective speed training methodologies such as uphill sprints, downhill sprints and sled resisted sprints appears to be effective at improving sprinting speed

and sprint momentum. Previous studies that have examined long term physical changes in the different contact football codes have noted continuous increases in strength until players hit their mid-twenties (Appleby et al., 2012; Baker, 2013; Jacobson et al., 2013; McGuigan, Cormack, & Newton, 2009; Miller et al., 2002; Stodden & Galitski, 2010). The players in Study 3 were able to effectively improve their sprinting speed for a longer period of time than has been noted for American football players (Jacobson et al., 2013; Miller et al., 2002; Stodden & Galitski, 2010). The strength training that was performed by the athletes in Study 3 was probably similar to the studies of American football players. The greater improvement in sprinting speed may have been because of the focus placed on specific sprint sessions utilizing different effective sprint training methods such as hill sprints and sled sprints (Lockie, Murphy, & Spinks, 2003; Paradisis et al., 2009). The short competitive seasons and long off-seasons in American football allow for a much greater focus on physical development than rugby union so it possible that American football players just hit the peak of their sprinting ability quicker. It can be concluded that sprinting speed is very much a trainable quality in rugby union players and a specific focus can be placed on the development of sprinting speed in players in their late teens and early twenties.

The aim of the experiment in Study 6 was to try and identify a method of producing changes in sprinting speed in players who had otherwise plateaued in improving this physical quality. It was hypothesized that the hypergravity condition would be effective at improving sprinting speed given how effective it had been with the two players in the pilot study. The two players who participated in the pilot study were the two fastest players in the squad and both achieved lifetime personal bests in their

speed over the first 10 m of a sprint. It was expected that the experimental group would've made the same changes but this was not the case. This may have had to do with the heavy conditioning that all of the players were involved in. Further research is required to determine if this method can successfully be used to improve sprinting speed of rugby players.

9.2 Practical Application

Based on the findings from this thesis, the following practical recommendations are made for developing a comprehensive speed testing battery and prescribing effective training programs to improve sprinting speed.

- Program design for improving sprinting speed and sprint momentum of rugby players should consist of comprehensive speed testing protocols that assess different sprint phases, assess sprinting kinematics, assesses ball carrying ability, and considers the players sprint momentums with ideal positional standards.

- It is recommended to use splits rather than a single longer distance such as a 40 or 50m sprint in order to evaluate performance in different phases of a sprint. If multiple gates can be set up, it would be worthwhile to use a 0-5m split to evaluate *Initial Acceleration*, a 5-10 m split to evaluate the *Mid-Acceleration* phase, a 10-20 m split to evaluate the *Transition to Maximal Velocity* phase, a 20-30 m split to evaluate the beginning of the *Maximal Velocity* phase and a 30-40 m split to evaluate the peak sprinting velocity in the *Maximal Velocity* phase. If four pairs of timing gates are available, then gates can be set up at

the start and 10 m to measure a combined *Acceleration* phase and at 30 m and 40 m to measure a *Maximal Velocity* phase. If only two timing gates are available, a 10 m split from standing sprint can be used to measure *Acceleration* and a flying 10 m split with a 30 m approach can be to measure *Maximal Velocity*.

- Players should be sprint tested while carrying the ball in one hand and two hands to identify if they have a deficiency carrying the ball in two hands or their non-dominant hand during both acceleration and maximal velocity phases. If an individual is found to be deficient at carrying the ball in two hands, it may be beneficial to include ball carrying drills during speed training sessions.

- High speed video cameras and software to analyze video have become considerably less cost prohibitive, and as such an in depth assessment of sprinting kinematics can realistically be performed in many settings. High speed video cameras can be used to record sprinting kinematics if metrics such as stride length, frequency, and ground contact time are being monitored in response to specific training interventions. Assessing sprint qualities in this manner will allow for training programs to be designed to address specific weak areas in the overall sprint performance. High speed cameras can also allow for qualitative assessment with the camera as well as give insight into potential for improvement in kinematics such as ground contact time or stride length.

- Sprint momentum should be calculated by multiplying the body mass of athletes with a velocity measure calculated from one of the acceleration splits

and one of the maximal velocity splits so that *Initial Sprint Momentum* and *Maximal Sprint Momentum* measures can be determined.

- Strength training programs emphasizing plyometrics, variations of the Olympic lifts and squats are likely helpful at increasing sprinting speed in developmental rugby players. Increasing performance of these exercises will likely results in an increase in a stride length and a decrease in ground contact time of players. As the training background of rugby players grows, these exercises will likely have less and less of a positive effect on improving sprinting speed specifically.

- High body mass is important for most rugby positions and increasing sprint momentum will mainly be improved by increasing body mass. Players can increase body mass without fearing a loss of sprinting speed as long as the strength training program involves plyometrics and places an emphasis on increasing lower body power.

- Combining a program of the above mentioned strength and power exercises with regular speed training sessions that utilize many speed training methods such as sled resisted sprints, uphill sprints and downhill sprints will lead to an increase in sprinting speed and sprint momentum. Sprinting speed and sprint momentum can both be improved in junior players transitioning into senior rugby but senior players may only be able to improve sprint momentum.

- A simulated hypergravity condition may have some potential benefit for increasing speed and power of players. It likely is ineffective if done at the same time as regular rugby training involving heavy aerobic conditioning.

9.3 Areas for Future Research

The research presented in this thesis has contributed to the field of knowledge in several useful ways but many areas still need to be investigated in order to come up with more concrete training guidelines for improving sprinting speed. The process of training elite athletes is likely much more complicated than the idea that improving by a certain amount on one exercise will lead to a predictable amount of improvement in sprinting or jumping performance. The combination of exercises in a training session and the placement of training sessions within a week may be more relevant for elite athletes. Sprinting speed is unquestionably an important physical ability for rugby players but the ability to combine it with change of direction skills is just as important. Players probably reach a point in their career where improvements in sprinting speed are no longer possible but improvements in change of direction skills are possible. With these facts in mind, the following areas need further investigation:

1) Change of direction skills such as swerving and side-stepping are of great importance (Wheeler & Sayers, 2010, 2011) but more in depth research is needed to describe the exact biomechanics of these movement and how players who excel at change of direction skills are able to transition from sprinting to change of direction movements and back to sprinting again. An in

depth understanding of these skills will lead to more effective coaching strategies.

2) Ground contact times are short during maximal sprinting velocity and are characterized by high eccentric loads (Mero & Komi, 1994). It would be worthwhile for future research to examine whether or not plyometric exercises such as drop jumps, that also have short ground contact times and high eccentric loads (Barr & Nolte, 2014), lead to improvements in sprinting through a decrease in ground contact time.
3) The placement of strength training sessions before speed sessions in a day has been shown to lead to improved sprinting performance later in the day (Cook, Kilduff, Crewther, Beaven, & West, 2014). Future research should examine whether volume-equated programs have different outcomes on sprinting speed based on the placement of the speed sessions during the week.
4) The placement of strength training exercises immediately prior to speed training drills has been shown to improve sprinting speed through a post-activation potentiation effect (Comyns, Harrison, & Hennessy, 2010). Future research should look to examine training programs that combine speed and strength training drills into the same session to take advantage of this effect.
5) Exercises that involve performing underweighted or assisted movement such as jumping (Sheppard et al., 2011) and throwing (DeRenne et al., 2001) have been effective at improving performance. It would be beneficial to see if performing sprinting through a mechanism of vertical assistance (Kratky & Müller, 2014) could lead to improved sprinting speed.

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