Applied Physiology of Rugby Sevens: Performance Analysis and Elite Player Development

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Abstract

Rugby sevens is an abbreviated format of rugby union that will be contested at the Olympic Games from 2016. Despite a rise in the worldwide popularity and profile of rugby sevens, the technical, tactical, physical, and physiological demands of international competition are not well understood and only limited information exists on the characteristics of elite-level players. The purpose of this thesis was to quantify the requirements of international competition, identify the anthropometric, physiological, and performance characteristics of international-level players, and quantify the specificity of contemporary on-field training practices. Seven experimental studies were conducted to address these issues.

Linear mixed modelling of 392 international team performances identified several performance indicators either positively or negatively related to the number of points scored by a team. An increase of two standard deviations in a team’s possession time (4.0; ±2.0, change in points scored; ±90% confidence limits (CL)), passes (1.0; ±1.5), kicks (1.1; ±1.5), and relative ruck and maul retention (5.9; ±1.4) were related to scoring more points in a match. In contrast, opposition possession time (-5.8; ±1.8), penalties and free kicks conceded (-2.2; ±1.5), passes per min of possession (-1.7; ±1.5), rucks and mauls retained (-3.0; ±1.5), rucks and mauls per min of possession (-8.8; ±1.3), turnovers conceded (-7.0; ±1.4), and turnovers conceded per min of possession (-8.0; ±1.6) were negatively related to scoring points. Linear mixed modelling of performance indicators from nine tournaments of the 2011/2012 International Rugby Board (IRB) Sevens World Series confirmed the most successful teams maintained ball possession by minimising errors and turnovers, were efficient in converting possession into tries, and had effective defensive structures resulting in a high rate of tackle completion. Similarly, linear mixed modelling of performance indicators for 12 teams during four IRB Sevens World Series between 2008/2009 and 2011/2012 revealed the mean number of tries scored and conceded by a team best discriminated higher and lower World Series rankings within and between teams. Tactics associated with a better team ranking were based on increasing ball retention in line-outs and the breakdown, turning the ball over more frequently in opposition rucks, and pressuring the opposition in their territory by kicking fewer contestable restarts.

Activity profiling of 174 player observations during 27 matches demonstrated a higher physical intensity in international compared with domestic matches due to players covering
~27% greater distance at ≥6 m·s⁻¹ and performing 4 to 39% more changes in velocity. Total distance covered per min was ~45% greater in rugby sevens and relative high-velocity running volume more than double that of 15-player rugby union. Despite 1 to 16% reductions in the distance covered at >2 m·s⁻¹ and number of changes in velocity from the first to second half of matches, there was little indication of accumulated fatigue over a multi-day tournament.

Laboratory- and field-based testing of 18 international male rugby sevens players revealed they had highly-developed speed, power, and endurance qualities to meet the demands of competition. Rugby sevens players had anthropometric characteristics similar to those of backs in international 15-player rugby union. Acceleration and speed, lower-body muscular power, and relative maximal aerobic power were similar to, or exceeded, that of professional 15-a-side players. The small between-athlete variability of characteristics in rugby sevens players highlights the need for relatively uniform physical and performance standards in contrast with 15-a-side teams.

The body composition of 38 international male rugby union and 27 international male rugby sevens players was measured using dual-energy X-ray absorptiometry. The quantity and distribution of fat, non-osseous lean and bone mineral mass across anatomical regions were compared between backs and forwards in each squad. Forwards were heavier and had a greater quantity of fat (union 43 to 67%; ±~17%, range of % differences; ±~95% CL; sevens 20 to 26%; ±~29%), non-osseous lean (union 14 to 22%; ±~5.8%; sevens 6.9 to 8.4%; ±~6.6%), and bone mineral (union 12 to 26%; ±~7.2%; sevens 5.0 to 11%; ±~7.2%) mass than backs in both rugby union and rugby sevens. However, the magnitude of difference between the positional groups was greater in rugby union players. When anatomical regional tissue mass was expressed as a proportion of total regional mass, positional group differences were predominantly unclear in rugby sevens players, but persisted in rugby union players. The distribution of tissue varied between positional groups and rugby formats.

The movement patterns and physiological demands of 42 international male rugby sevens players were monitored during 22 international matches and 63 rugby-specific training drills. Differences between matches and training were quantified using magnitude-based inferential statistics. During 21 months of on-field training observation, technical and game-simulation drills typically failed to replicate the positional group-specific physical and physiological demands of competition.
In summary, rugby sevens imposes unique demands on players during competition. The disparity between rugby union and rugby sevens dictates different characteristics of players, priorities for player preparation, and tactical approaches to competition are required. Coaches and support staff can utilise the findings of this thesis to better prepare players for the requirements of this growing sport. The research outcomes can be applied to develop talent identification and transfer programmes, refine positional group-specific technical and physical development, and implement monitoring systems to ensure training adaptations are optimised leading into international competition in the newest Olympic team sport.
Statement of Contribution by Others

This thesis details original research conducted by the candidate at the Australian Institute of Sport while enrolled in the Faculty of Health at the University of Canberra. The thesis includes research articles of which I am the lead author and was primarily responsible for the conception and design of the research, ethical approval to conduct the research, data collection, analysis and interpretation, manuscript preparation, and correspondence with journals.

Where explicitly acknowledged in each experimental chapter, a number of individuals have contributed to the research presented in this thesis.

- Prof. David B. Pyne: Research design, data interpretation and manuscript review
- Dr. Judith M. Anson: Manuscript review
- Prof. Will G. Hopkins: Data analysis and interpretation, and manuscript review
- Dr. Gary J. Slater: Data collection and interpretation, and manuscript review
- Christine E. Dziedzic: Data interpretation and manuscript review
- Anthony Eddy: Technical assistance

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Signature of candidate (Dean Higham)

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Signature of chair of the supervisory panel (Dr. Judith Anson)

Date: ........................................
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“If I have seen further, it is by standing on the shoulders of giants” - Sir Isaac Newton

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Chapter One - Introduction

Rugby union is an international field-based team sport characterised by frequent physical contact and repeated intermittent bouts of high-intensity activity. Success in the sport at an elite level requires well-developed physical and physiological characteristics, technical expertise in a diverse range of skills, perceptual and strategic awareness, and the ability to implement team tactics. The development of players to compete on the international stage therefore, also necessitates a multifaceted and competition-specific approach to concurrently improve players’ physical, physiological, technical, and tactical capabilities.

Despite an increase in global popularity and competitiveness, and the importance of player development for performance, the evidence base of applied research has failed to keep pace with the increased professionalism in rugby union and its abridged format, rugby sevens. Although previous research has attempted to quantify rugby union and rugby sevens activity profiles during competition [207,241], characterise the anthropometric and physiological qualities of players [78], and assess training interventions [4,110], the changing demands of competition and the need for practical applications of scientific research warrant contemporary investigation. Furthermore, in parallel with the changing demands of competition and physical preparation programmes, there have also been developments in the methods available for data collection and analysis. For example, it is now possible to concurrently quantify a player’s heart rate, physical impacts, distance covered, and velocity in real time without interference to the training and match environment [12,65]. Progressive methods of data analysis and interpretation now allow for the practical as well as statistical significance of empirical findings to be quantified [141]. The coalition of these factors highlights the need for a comprehensive assessment of the competition demands and technical and physical development of elite-level players, especially in the emerging sport of rugby sevens.

Although greater professionalism in rugby union has stimulated scientific interest, there remains a paucity of information on the specific requirements for player development in rugby sevens. Differences in the competition demands between rugby union and rugby sevens suggest the requirements of an evidence-based technical and physical preparation programme will also differ [175]. The simple application of elite-level player development programmes for rugby sevens based on the needs of rugby union competition is
inappropriate. The development and implementation of a rugby sevens-specific development programme should be primarily dictated by the demands of competition. The technical, tactical and physiological demands of competition can be evaluated by monitoring elite-level performance [213] and profiling international-level players to identify key characteristics specific to the sport [172]. Once the demands of competition have been established, the specificity of talent identification and development programmes, and training practices, can be explored and optimised. The explicit physical and physiological outcomes of training activities may be compared to those of competition to help guide physical preparation programmes [128]. To date, no published investigations have examined the typical training practices of rugby sevens players. Although the specialisation of player development towards either rugby union or rugby sevens has increased in recent years, many fundamental areas of technical and physical preparation require further rigorous scientific investigation.

**Statement of the Problem**

Little information exists on the requirements for optimal individualised development and preparation programmes for international-level rugby sevens players. Establishing such programmes requires an evidence-based approach addressing the technical, tactical, physical, and physiological priorities to meet the demands of competition. The conception and delivery of competition level-specific preparation programmes relies on an understanding of the demands of competition and the requirements for success. The limited scientific literature detailing rugby sevens players and competition leaves coaches and support staff to currently rely on personal experience and anecdotal reports when planning player preparation programmes.

The key performance indicators and patterns of play related to successful team performance in contemporary rugby sevens competition are not well understood. Despite match statistics on international competitions being available to coaching and support staff, it is unclear which performance indicators are most important for monitoring team performance. To date, there are no thorough published retrospective investigations of team performances, needed for successful preparation and prediction of competition outcomes. Given the inherently variable nature of rugby sevens, it is difficult for coaches to address the technical and tactical priorities for training without this knowledge.

The global increase in popularity of rugby sevens has seen a corresponding increase in the number of tournaments played at the domestic and international level. For rugby sevens
players and coaches, the transition from the domestic to international stage is an important consideration. To date, there is no scientific review of the likely differences in movement patterns between international- and domestic-level tournaments. Unlike rugby union, which is typically played in a seasonal league-style competition format, rugby sevens competitions are played in a tournament-style format involving up to six matches played over two or three days. The potential effect of accumulated fatigue on players’ movement patterns over multiple matches within and between competition days has not been examined.

Although the physical characteristics and physiological capacities of rugby union players have been reported [78], this information is not available on rugby sevens players. A comprehensive understanding of the anthropometric, physiological and performance characteristics of elite-level rugby sevens players, and how they differ from professional rugby union players, is needed to guide talent identification and development programmes, individualise training prescription and injury prevention programmes, and facilitate the transition of players to the more specialised sevens format. Sport-specific strength and conditioning programmes rely on an understanding of the association between the anthropometric and fitness attributes of players. This association is currently unknown in rugby sevens players. Furthermore, at present there is a gap in understanding of the relationships between cross-sectional player evaluations in the laboratory and in the field, and on-field monitoring of training and competition.

Given the traditional crossover of players and coaches between rugby union and rugby sevens, it is not uncommon for training activities typical of rugby union to be used to prepare rugby sevens players. This approach may be inappropriate as the competition demands and requirements for positional group-specific physical development in international rugby sevens differ markedly to rugby union [175]. The effectiveness and specificity of training drills used to concomitantly improve the physical, physiological, technical and tactical capabilities of players has not been scientifically scrutinised.

**Aims**

The specific aims of the experimental studies contained within this thesis are to:

**Competition Analysis**

1. Identify key performance indicators related to successful rugby sevens performance.
2. Develop models for rugby sevens match performance prediction using team performance indicators.

3. Identify the relationship between team performance indicators and international rugby sevens tournament outcomes.

4. Identify specific technical and tactical factors (patterns of play) associated with success in international rugby sevens.

5. Quantify the differences in movement patterns between international and domestic rugby sevens tournaments.

6. Quantify changes in movement patterns within and between rugby sevens matches.

7. Assess the movement patterns of late-match substitute players in rugby sevens matches.

**Player Selection and Development**

8. Profile the physiological, anthropometric and performance characteristics of national-level rugby sevens players, and compare these results with previously published values for rugby union players.

9. Quantify the relationships between anthropometric, physiological and performance test results in national-level rugby sevens players.

10. Quantify and compare the distribution of fat, non-osseous lean and bone mineral mass in international rugby union and rugby sevens players.

**Specificity of Training**

11. Examine the positional group-specific specificity of contemporary rugby sevens training practices in relation to the demands of competition.

**Significance of the Thesis**

The findings of this thesis have a direct and practical application for the analysis of contemporary rugby sevens performance and delivery of player development programmes. The examination of current competition and training performance should allow for more effective individualisation of training and recovery programmes. The outcomes of the investigations contained within this thesis will guide player development programmes for technical and physical preparation as well as the priorities of national coaching curricula. Furthermore, the research findings will assist the direction of sport-specific talent identification and development systems.
By quantifying the specific demands of training drills, coaching and support staff may implement strategies designed to maximise training effectiveness. Given the limited time available to players and coaches for training and physical development, the efficiency of training must be optimised to minimise the risks to players’ health and performance without compromising training adaptations. Understanding movement patterns and physiological demands of various training drills, and the disparity between training and match demands afforded by this thesis, provide a useful scientific framework for coaches in prescribing periodised training programmes.

**Synopsis of the Thesis**

This thesis contains eleven chapters. Each experimental chapter of the thesis (chapters three to nine) is presented in manuscript format according to the requirements of the scientific journal to which it was submitted, with corresponding Abstract, Introduction, Methods, Results and Discussion sections. Consequently, there is some repetition between chapters in the thesis. Experimental chapters vary from the published articles in some sections due to minor editorial changes and the addition of supplementary information. For the reader’s benefit, all references are placed at the end of the thesis. A thematic overview of the progression of the experimental chapters within the thesis is shown in Figure 1.1.

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**Figure 1.1.** Thematic overview of the experimental thesis chapters.
Following Chapter One – Introduction, Chapter Two – Review of Literature details a contemporary review of the major applied physiology and performance topics relating to rugby union and rugby sevens. The review includes an introduction and background of rugby union and rugby sevens, details of performance analysis in rugby union, physical characteristics and physiological capacities of rugby players and associations with performance, and a summary of physical development and training interventions.

Chapter Three – Performance Indicators Related to Points Scoring and Winning in International Rugby Sevens examines the team statistics of international rugby sevens matches to identify which technical performance indicators are best associated with team performance. Key performance indicators are used to develop models to predict the number of points scored by a team and the likelihood of victory in close matches.

Chapter Four – Relationships between Rugby Sevens Performance Indicators and International Tournament Outcomes investigates the association between performance indicators of international rugby sevens teams and their final ranking in tournaments.

Chapter Five – Patterns of Play Associated with Success in International Rugby Sevens explores the association between the tactics and patterns of play adopted by teams over the course of an international season and their final ranking in the International Rugby Board (IRB) Sevens World Series.

Chapter Six – Movement Patterns in Rugby Sevens: Effects of Tournament Level, Fatigue and Substitute Players documents a comprehensive analysis of the activity profiles of players during domestic- and international-level matches using Global Positioning System (GPS) technology. Movement patterns are analysed using magnitude-based statistics to make inferences on the practical applications of results, specifically relating to competition level-specific preparation, the effects of acute and residual fatigue, and tactical considerations to mitigate the effects of fatigue on team performance.

Chapter Seven – Physiological, Anthropometric and Performance Characteristics of Rugby Sevens Players and Chapter Eight – Distribution of Fat, Non-osseous Lean and Bone Mineral Mass in International Rugby Union and Rugby Sevens Players profiles the characteristics and capacities of rugby sevens players and how these characteristics and capacities compare to those of professional rugby union players. In conjunction with the examination of
competition demands outlined in previous chapters, chapters seven and eight define the priorities for physical development of elite-level rugby sevens players.

Chapter Nine – Comparison of Activity Profiles and Physiological Demands between International Rugby Sevens Matches and Training examines the specificity of different types of on-field training in a cohort of international rugby sevens players. This investigation should assist the development of sport-specific training drills to provide physical and physiological stimuli similar to those observed during competition. Coaching staff can use the results of the study to mediate the stress placed on players by increasing the specificity and intensity, and reducing the volume, of training.

Chapter Ten – Discussion reviews the impact of this thesis and its importance in the progression of knowledge in the area of applied physiology in elite-level rugby sevens.

Chapter Eleven – Research Outcomes presents the primary findings of the thesis, practical outcomes and applications of the new knowledge, limitations of the research, and directions for future research in the area.

The thesis is supported by additional work presented in the appendices. The appendices include a review manuscript submitted for publication that details the physique characteristics and training patterns of international-level rugby sevens players, the physical and physiological demands of competition and subsequent practical nutritional guidelines likely to enhance performance during international tournaments (Appendix A). Also included in the appendices are international scientific conference presentation abstracts that describe the competition movement patterns in rugby sevens (Appendix B) and the physical and performance qualities of rugby sevens players (Appendix C), compare the fitness characteristics of male and female players (Appendix D), and compare the validity and reliability of GPS devices for measuring sprint distances in team-sport athletes (Appendix E).
Chapter Two - Review of Literature

Evolution of Rugby Union

Rugby union is a contact, field-based team sport played by over five million people around the world [45]. A match is played over 40-min halves with a short break between, during which teams exchange ends of the field. Two teams begin each match with 15 players on the field who may be substituted (tactical) or replaced (injury) during the match. Each team may nominate up to seven or eight replacement/substitute players depending on the level of competition. Players are classified into two main groups based on playing position and their role within the team. The “forwards” are player numbers 1 to 8 and the “backs” are numbered 9 to 15 (Table 2.1). The principal function of forwards is to contest possession in set-piece plays as well as rucks and mauls, while the role of backs is to use possession to gain territory and score points. When not in possession, backs attempt to prevent the opponents from gaining territory and scoring through tackling. In Australia, the typical competition season is contested between February and September with usually one or, at most, two matches played in any 7-day period.
Table 2.1. Numbers, positions, groups and sub-groups in rugby union.

<table>
<thead>
<tr>
<th>Number</th>
<th>Position</th>
<th>Group</th>
<th>Sub-group</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Loose-head prop</td>
<td>Forwards</td>
<td>Tight five</td>
</tr>
<tr>
<td>2</td>
<td>Hooker</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Tight-head prop</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Left lock</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Right lock</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Blindside flanker</td>
<td></td>
<td>Loose forwards</td>
</tr>
<tr>
<td>7</td>
<td>Openside flanker</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Number eight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Scrum-half</td>
<td>Backs</td>
<td>Halves</td>
</tr>
<tr>
<td>10</td>
<td>Fly-half</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Left wing</td>
<td></td>
<td>Outside backs</td>
</tr>
<tr>
<td>12</td>
<td>Inside centre</td>
<td></td>
<td>Centres</td>
</tr>
<tr>
<td>13</td>
<td>Outside centre</td>
<td></td>
<td>(mid-field backs)</td>
</tr>
<tr>
<td>14</td>
<td>Right wing</td>
<td></td>
<td>Outside backs</td>
</tr>
<tr>
<td>15</td>
<td>Fullback</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The international popularity of rugby union continues to grow, with worldwide participation increasing by 19% between 2007 and 2010 and the sport’s governing body, the IRB, encompassing 118 national unions [45]. Accompanying this increased popularity is modification of the laws of the game and development of non-traditional game formats such as rugby sevens. These developments are primarily aimed at increasing player welfare, promoting public and commercial interest, and facilitating the diffusion of rugby union into new demographics and emerging markets. As a consequence of the dynamic nature of rugby union and the increased popularity of rugby sevens, applied research into the physical preparation and development of elite-level players is a continuing process. With the evolution of training methods, equipment technology, player characteristics, law changes, and patterns of play [85,193,205,228,276], the utility of previous scientific investigations is quickly becoming limited. Accordingly, data collected on players prior to the professionalisation of rugby union in 1995 are not within the scope of this review and have been excluded. Previous reviews have summarised much of the preceding literature on amateur and early professional rugby union [78,187,212]. Due to a paucity of existing scientific literature on female players...
and the focus of the research supporting this thesis being male players, this review has been limited to descriptions of male rugby union and rugby sevens players, with particular reference to contemporary professional and elite-level players.

**Description of Rugby Sevens**

Rugby sevens is an abbreviated variant of rugby union in which each team has a maximum of seven players on the field. Rugby sevens matches are played on a standard dimension rugby union playing field but are shorter in duration, consisting of 7-min halves with a 2-min half-time interval. A competition final match can be played over two 10-min halves. In the IRB Sevens World Series, only the Cup final, which determines the overall winner of an event, is played with 10-min halves. Rugby sevens competitions are different from 15-player rugby union and are usually played over 2- or 3-day tournaments with teams playing up to three matches per day with approximately 3 hours between each.

A rugby sevens team is composed of three forwards, four backs and five replacements/substitutes. Due to the fast nature of the game, rugby sevens players usually compete as backs or back row (loose) forwards in 15-player rugby union. Although most players compete in both forms of the game, and rugby sevens is often used as a development stage in the career of younger players, it is becoming increasingly specialised. Rugby sevens is played under substantially the same laws as rugby union with several variations primarily aimed at speeding up the game and to account for the reduced number of players.

Rugby sevens originated in Melrose, Scotland, where it was first played in 1883 as a fundraising event. The first officially sanctioned international tournament was played in 1973 at Murrayfield, Scotland. The popularity of rugby sevens has spread rapidly in recent years and the sport is now played all over the world. Internationally, rugby sevens is often regarded as being more competitive than rugby union owing to the nature of the game. As IRB Chairman, Bernard Lapasset, stated at the conclusion of the 2009/10 IRB Sevens World Series:

> In the last two seasons alone eight countries from four continents have won Cup titles - New Zealand, South Africa, Fiji, Samoa, Australia, Argentina and England [are] all winners on the World Series, and Wales at the Rugby World Cup Sevens and we have seen the emergence of other title contenders such as Kenya and USA, who have reached Cup finals. [148]
Rugby sevens has become popular in nations which are not traditionally successful in the 15-a-side format. Development in nations where rugby union has a lesser profile has often focussed on rugby sevens as a means of introducing people to the sport.

The growing worldwide popularity of rugby sevens was highlighted in October, 2009 when the International Olympic Committee voted to include rugby sevens on the sporting programme for the 2016 Summer Olympic Games in Rio de Janeiro, Brazil. The introduction into the Olympic Games compliments other multisport events where rugby sevens is currently contested such as the Commonwealth Games, Asian Games, Pacific Games and World Games. Other major international rugby sevens tournaments include the IRB Sevens World Series and the Rugby World Cup Sevens. The men’s IRB Sevens World Series is contested annually over nine rounds played in various locations around the world. The Rugby World Cup Sevens is held every four years. Following the 2013 tournament in Moscow, Russia, the quadrennial Rugby World Cup Sevens event will be integrated into the middle of the Olympic cycle, with the next tournament to take place in 2018.

**Performance Analysis in Rugby Union**

Performance analysis is a relatively new sub-discipline of sports science primarily related to the observation and deconstruction of an individual player or team performance. Accurate examination and evaluation of performance is a key component of successful coaching. Consequently, the role of performance analysts in supporting coaching staff is becoming more prevalent with the assistance of increasingly sophisticated technology. Success in team sports such as rugby union and rugby sevens relies upon the consistent execution of performance through the development of technical, strategic, physiological, and psychological factors. Performance analysis in these sports is principally focused on the technical and strategic domains using notational analysis, and the physiological domain through time-motion analysis.

**Notational Analysis**

Notational analysis is a method used to objectively and reliably quantify critical moments in a performance [143]. Many aspects of rugby union performance, from individual players [37,150,164] to team units and entire teams [152,153,165,260], have been characterised using notational analysis. Of particular interest to sports scientists and coaches are the “set-piece” elements of performance, such as line-outs and scrums, as well as the offensive [35,75,161,165,259,272,273] and defensive structures, patterns, and outcomes [257,258].
Many performance analysis studies have attempted to identify tactics and technical skill executions associated with scoring tries and team success [35, 75, 161, 165, 259]. These studies highlight a variety of tactics and playing styles that teams may employ with equal effectiveness. The playing styles associated with successful team outcomes not only differ between competitions, but also within tournaments [259]. Despite these variations, there are common elements of performance at either an individual player or team level more often predictive of success. These elements are commonly termed “performance indicators”. Performance analysis research is often used as a vehicle to identify key performance indicators in team sports such as rugby union and rugby sevens.

**Performance indicators**

A performance indicator is a variable, or combination of variables, that attempts to explain some aspect of performance [146]. To be useful and representative of a performance, performance indicators should be related to a successful performance or outcome, and are often expressed as a ratio or normalised relative to a predetermined value to facilitate comparisons within and between teams or individuals. Performance indicators can be subcategorised into four types: match classification indicators, technical indicators, tactical indicators, and biomechanical indicators.

Match classification indicators define the nature of the match by reporting the frequency of key structural events. These indicators describe the overall performance and are most appropriately interpreted in relation to the opponents’ values and previous performances at a similar standard. Examples of match classification indicators in rugby union are tries, penalties and drop goals (successful and unsuccessful), line-outs, scrums, and incursions into the opponents’ 22-metre zone.

A technical indicator reflects the relative success in execution of a specific skill. The frequency of success or error in technical skill performance is typically normalised against the total frequency of skill executions and reported as a ratio or percentage. Examples of technical indicators include successful conversions, tackles missed, passes completed, and scrum possessions retained.

Tactical indicators illustrate the decision-making options taken by a player, unit, or team based on their technical strengths and weaknesses, thereby reflecting the style or patterns of play employed. In rugby union it is possible to quantify, and express in either percentages or ratios, the options taken to kick, run, or pass the ball when in possession. Other performance
indicators representing a team’s chosen style of play include the number of rucks or passes per min of possession. These values typically reveal the preference for a team to employ either a direct or wide attacking approach.

The ability of teams to successfully employ a strategy or tactic is constrained by their capacity to accurately execute individual skills. Biomechanical indicators are used to describe and assess the technique of an individual or group performing a skill. Despite the rich information the assessment of the technique of skill execution could add to other outcome-focused measures, the use of biomechanical performance indicators in rugby union research is limited [130,206,208,222,272,273]. Biomechanical indicators vary from descriptive to the kinetics and kinematics of skill performance. Examples include the analysis of ball release velocity, to analysis of energy transfer, joint forces and moments, and sequencing of joint movements. Skills that may benefit from further quantitative and qualitative analysis of technique include scrummaging, tackling, passing, kicking, and line-out lifting, jumping and throwing.

Investigations of contact skills of rugby union players have provided insight on the technical predictors of success in the tackle contest. In attack, strong contact intensity and active fending strategies predicted 86% of poor defensive positions, with 92% of tackle breaks occurring as a result of poor defensive positioning [272]. Players are also more likely to be successful in the tackle and produce a positive phase outcome when receiving the ball at higher speeds, running with greater intensity, and adopting either an oblique running pattern or a forward step evasion pattern [223]. Furthermore, higher-ranked teams had a larger percentage of tackle breaks, higher ball reception speeds and greater running intensity than lower-ranked teams [223,273]. Conversely, forward lean of the tackler’s torso and an oblique angle of approach to the ball-carrier were more prevalent characteristics of effective tackles resulting in a net loss or zero gain in attacking territory from the time of contact to the completion of the tackle [257]. The number of tackle attempts varies between positional groups and between competitions, even at the international level [258]. These differences presumably reflect variations in playing style and the unique role of individual playing positions in influencing the frequency, velocity, and type of tackle attempted.

Researchers have attempted to validate key performance indicators in rugby union and rugby sevens by investigating their relationship with performance outcomes, such as tournament rankings, or examining the differences in performance indicator values between winning and
A case study of twenty matches of one professional team in a domestic league revealed statistically significant differences between winning and losing performances for the percentage of line-outs won on opposition’s throw, and the percentage of tries scored out of the total tries scored [153]. Differences not statistically significant but possibly of practical importance were observed for turnovers and errors made. The performance indicators discriminating between winning and losing teams vary depending on the specific competition and how close or balanced the match is [263,264]. Analyses of 58 matches over four seasons of the Six Nations tournament (2003 to 2006) demonstrated several key differences in performance indicators between winning and losing teams [195]. Briefly, winning teams lost less possession during scrums and line-outs, won more turnovers and mauls, completed more tackles, kicked more frequently, and made more line breaks.

The limited research investigating performance indicators in rugby sevens shows that successful teams are dominant in defence as well as offence [144]. Successful teams appear to play a different style of game from unsuccessful teams. Successful teams obtained more territory and possession, performed fewer rucks, mauls and kicks, and executed more dummy passes, sidesteps, swerves, and clean breaks. The possession advantage of successful teams resulted in fewer tackles being made, but also fewer missed tackles than unsuccessful teams. However, the application of these findings from matches played in 2001 to modern international-level rugby sevens is uncertain given the rapid evolution of the sport in recent years. More recently, a regression analysis of the mean performance indicator value per match over seven tournaments of the IRB Sevens World Series revealed tries per match, rucks per match, and passes per match accounted for 93% of the variance in the team’s final ranking [145].

Despite the range of analyses of rugby union performance, critical gaps still remain in the knowledge of successful performance and application of methods to prepare players for competition. Research outcomes for coaching may benefit from investigation of individual elements of performance, and the amalgamation of performance indicators to give a more complete summary of team structures and strategies. Given advancements in measurement and analysis technology, off-the-ball player formations and player interactions and coordination can be studied to further explain rugby performance and aid player preparation [53,197,198]. It is also evident there is a lack of published information available on rugby sevens performance. There is great potential for the progression of performance analysis.
research in rugby sevens competition to expand the knowledge of performance and coaching in this sport.

**Time-motion Analysis**

Time-motion analysis is a method used to quantify the dynamic movement patterns and energetic demands of training and competition. Time-motion analysis simplifies the inherently variable and intermittent activity of players in team sports by quantifying and categorising the movement type, intensity, frequency, and duration (and/or distance). The objective information provided by this analysis method can be directly applied to the design of sport- and position-specific physical preparation and testing programmes. There is a growing body of literature on the movement characteristics of contemporary professional rugby union competition [13,14,42,54,68,80,84,207,220,242]. However, only limited published data exist detailing the physical and physiological demands of men’s rugby sevens matches [115,216,239,241]. The collection of data on international-level rugby sevens players would greatly assist in accurately establishing the demands of competition.

Traditionally, rugby union time-motion analyses have been conducted using manual or computer-assisted notational analysis techniques [13,80]. Technological advancements now allow more sophisticated data collection and analysis methods to be used, including semi-automated player tracking systems [207] and micro-sensor technology such as GPS devices [12,65]. These methods have advantages over conventional notational analysis techniques including being substantially less labour-intensive, faster analysis and feedback times, greater objectivity, and improved accuracy and reliability, collectively making newer analysis methods a more viable option.

**Validity and reliability of time-motion analysis**

The validity and reliability of a measurement system is an important consideration when interpreting data collected during training or competition. Concurrent validity refers to the agreement between an observed value and the true or criterion value of a measurement, whereas test-retest reliability refers to the reproducibility of a value when a measurement is repeated [139]. A measurement system unable to produce accurate and consistent data has little use in the evaluation of sports performance. The interpretation of movement analysis data is dependent upon the reliability of the measurement method and estimations of the variability within and between players from observation to observation [79].
The validity and reliability must be established for each measurement technique used. Reliability and/or validity estimates have been derived for a variety of time-motion analysis techniques including computer-assisted and hand-notational analyses [73,74,79,139], a manual digitising analysis method [217], manual computer-based tracking [128], semi-automated player tracking [207], and GPS technology [12]. The intra-tester reliability of notational analysis, quantified as the typical error of measurement (TE) [139], of total duration spent in specific movements of stationary, walking, jogging, striding, sprinting, and static exertion are moderate to poor (5.8 to 11.1%), frequency of movements are good to poor (4.3 to 13.6%), and mean duration of movements are moderate (7.1 to 9.3%) [79]. Other studies using similar methods also report the intra-tester reliability (TE) of frequency of movements (1.2 to 4.6%), total duration (2.9 to 1.8%), mean duration (4.8%), percentage of total match duration in a specific movement type (4.3 to 1.6%), and percentage of total distance covered in specific movement types (3.7%) [13,73]. Inter-tester reliability is similar for all measures (0.4 to 8.7%) [13,73].

The validity and reliability of time-motion analyses estimating distances covered by players as the product of velocity, measured separately during different movement intensities (walking to sprinting) using timing gates, and time, measured by notational analysis, have also been reported. Validity estimates range from $r = 0.74$ to 0.94 for estimates of total distance covered at a variety of velocities, and $r = 0.45$ to 0.98 for estimates of mean distance covered [74]. Reliability estimates range from 1.7 to 4.9% standard error for estimated total distance and 1.9 to 4.9% standard error for mean distance [74]. The validity estimated for a manual digitising method, reported as a coefficient of variation, is within 2.1% for total distance covered and 8.3% for mean velocity [217]. Intra- and inter-tester reliability (TE) is 0.5% and 0.9%, respectively, for total distance, and 3.4% and 6.0%, respectively, for mean velocity [217]. These estimates are similar to the 6% intra- and inter-tester reliability reported for computer-based tracking [128].

More sophisticated methods are becoming increasingly common in the measurement and analysis of rugby union and rugby sevens players’ activity profiles. For example, semi-automated multiple-camera player tracking technologies offer a high degree of accuracy, with position data averaging between ±0.14 to 0.20 m, and a sampling frequency of 2 Hz or higher [84,207]. The practical advantages of micro-technology worn by players to monitor heart rate, physical impacts, distance covered, and velocity without interference to the training or match environment, and provide feedback in real time, means it is being increasingly adopted.
for player monitoring and research purposes. Reviews of the reliability, validity, and applications of GPS technology for measuring activity in field sports are described elsewhere [12,65]. However, it appears the validity of GPS measurements is enhanced with an increase in sampling frequency and longer measurement duration. Devices with a low sampling frequency (1 Hz) may be unable to accurately measure high-velocity activity performed over a short duration. This limitation is critical given the intermittent nature of field-based team sports. The reliability of GPS device measurements is also task- and time-dependent, with higher movement velocities and movements involving changes of direction showing poorer reliability. Newer GPS devices have sufficient accuracy to quantify instantaneous velocity, even during periods of acceleration and deceleration [262].

In the absence of a “gold standard” time-motion analysis method, all of the described techniques are capable of determining players’ movement patterns and work rates. Furthermore, a video-based time-motion analysis system, a semi-automated multiple-camera player tracking system, and GPS systems detect similar performance decrements during competition [211]. However, substantial differences in absolute measurement values suggest comparisons of information from different movement analysis systems require caution [124,211].

**Movement patterns**

Differences in match and environmental conditions, changes to the laws of the game, and variations in methodology make direct comparisons between research findings of player movement patterns difficult. However, it is clear from previous studies of rugby union players that substantial differences in movement patterns and activity profiles are evident between positions [207]. These disparities primarily relate to the playing roles of forwards and backs. Distinctions in the specific demands of individual positional groups should be acknowledged when structuring training and recovery programmes around competition.

The total distance covered by a player contesting an entire professional rugby union match ranges between approximately 4500 to 7500 m, with backs generally covering greater distances than forwards [13,42,54,68,220]. In relative terms, rugby union backs also cover greater distances per min (~71 to 74 m·min⁻¹) than forwards (~65 to 68 m·min⁻¹) [42,54,68]. In contrast, club-level rugby sevens players covered 1581 ± 146 m (mean ± SD; range 1349 to 1976 m) during an entire match [241]. If the distance travelled by rugby sevens players during a single match is normalised to an 80-min rugby union match, the total distance
covered would be approximately 9000 m. This theoretical extrapolation demonstrates the increased running intensity of rugby sevens competition, even at the sub-elite level. The distance covered by players during active (ball in play) time in international Rugby union matches varies between 3700 m for props to 4500 m for scrum-halves [207]. Players in various positions are stationary for between 9 and 15% of this active time. In both rugby union and rugby sevens, the majority of the total distance covered during a match is at a walking or jogging pace [13,42,54,68,207,220,239,241,242]. Rugby union backs spend more time walking (38 to 46%) than forwards (27 to 35%), while outside backs spend the greatest proportion of match time walking of all positional groups (43 to 62%) [80,84,220]. Conversely, backs tend to cover the greatest distance sprinting [13,54,68,84,220].

The mean duration of sprints during rugby union competition is approximately 2 to 4 s [73,83]. Mean sprint distances vary by position but are typically less than 20 m [14,68,74,84,242]. The mean sprint distance reported for backs (19.5 ± 6.5 m) and forwards (17.9 ± 3.6 m) in club-level rugby sevens matches is similar to that in rugby union [239]. However, comparisons between studies should be interpreted with caution because of differences in objective and more subjective methods of analysis, and varying definitions of a “sprint”. Despite the relatively short typical sprint durations in rugby union matches, players also regularly achieve speeds in excess of 90% maximal velocity [83].

Professional rugby union forwards spend approximately 2.5 times longer in high-intensity activity than backs [13,72,80,84,220]. The substantially greater high-intensity activity of forwards is attributable to more time involved in set-piece plays (scrums and line-outs) and contests for the ball (rucks and mauls) [13,72,73,80,84,207,220]. Set-piece plays and elements of the game involving collisions with opponents, namely rucks, mauls, and tackles, are critical components of a rugby union match. Rucks, mauls and scrums account for up to 11 ± 4% of match time for back-row forwards [80]. The same activities for backs account for >2% of total time [80,220]. As a proportion of time spent in high-intensity activity, forwards spend up to 90% in static exertion [72,73,220]. In contrast, between approximately 30 and 60% of high-intensity exercise in backs comprises running-based movements [72,220]. Back-row forwards typically complete more tackles than other positional groups, averaging up to 20 or more per match [80,84,207]. During an international rugby union match, forwards usually contest more than 30 rucks, whereas backs are rarely involved in more than half this number [207]. International-level forwards also usually contest around 25 scrums per match, with a mean duration of approximately 3 s from engagement to the completion of each scrum,
either through the ball being picked up by a player or the referee blowing the whistle for an infringement [207]. International-level forwards are typically engaged in around 3.5 min of scrums, rucks and mauls per match [207]. The total involvement of backs at the same level is less than 1 min per match. The mean duration for both backs and forwards of each scrum, ruck, or maul is 3 to 4 s.

The marked differences in the movement patterns and relative time spent in specific velocity zones between positional groups and individual positions in professional rugby union players are unsurprising given the diversity in playing roles. Forwards cover greater distances at low to moderate velocity resulting from more continuous activity, given their higher involvement and proximity to contests for the ball. The movement patterns and technical demands are distinct even between sub-groups of backline players. The scrum-half and fly-half handle and pass the ball more than any other positions, with the scrum-half handling the ball on 59 ± 10 occasions during an international match [207]. Scrum-halves cover the greatest distance of all positions at a velocity of 4 to 6 m·s$^{-1}$ [207]. In contrast, outside backs make less tackles than other positions and spend a large proportion of match time in off-the-ball activities which is reflected by the large distances covered walking and in utility movements (lateral or backward walking and shuffling) [73,80,84,207,220]. When outside backs are involved in play, they cover large distances sprinting to support other players, cover in defence, gain territory, and score tries [73,80,84,207,220].

Quantifying the work-to-rest ratios of competition provides valuable and objective information for the development of competition-specific physical preparation programmes. Comparisons between reports of work-to-rest ratios and the frequency and duration of efforts in the literature are confounded by differences in the definitions and methodologies employed. Mean work-to-rest ratios in professional rugby union matches vary from 1:4 for forwards [13] to 1:22.8 for outside backs [73] using video-based time-motion analysis methods, and 1:7.5 for back-row forwards to 1:14.6 for outside backs using a semi-automated multiple-camera player tracking system [84]. Using GPS technology, reports of mean work-to-rest ratios vary from 1:0.8 [242] to 1:5.8 [68]. Work-to-rest ratios reported for men’s rugby sevens competitions were derived solely on locomotion using GPS technology. Work-to-rest ratios were 1:0.5 [241] to 1:0.59 [239] based on movement at 0 to 1.67 m·s$^{-1}$ classified as rest and movements greater than a velocity of 1.69 m·s$^{-1}$ classified as work.
Differences in methodology and definitions make comparisons of the frequency and duration of work bouts difficult to interpret. The frequency of work periods for Super 12 rugby union players varied from $42 \pm 9$ (mean ± SD) periods per match for outside backs to $129 \pm 28$ for front-row forwards in one study [73] and $55 \pm 10$ for outside backs to $127 \pm 20$ for back-row forwards in another [80]. One study of English Premiership players reported $203 \pm 24$ high-intensity work bouts per match for outside backs with up to $275 \pm 44$ for back-row forwards [84], whereas another study reports a range of 102 for fly-halves and centres to 154 for loose forwards [220]. The mean duration of work bouts varies between positions and between studies from 1 to 6 s [73,80,84,220]. The short duration of work periods implies a significant reliance on anaerobic metabolism. Rest periods between work bouts are typically <20 s for most positional groups, whereas outside backs have substantially longer rest periods (>100 s) [80]. Short rest periods may be insufficient to allow full recovery of creatine phosphate stores, increasing the reliance on anaerobic glycolysis and oxidative metabolism [74,112]. Although most rest periods are relatively short, stoppages in play can increase the maximum rest time to between 3 and 7 min for different positions [73].

Descriptions of the mean work-to-rest ratios may be of limited use in preparing players for the most demanding passages of play. Analysis of the frequency, duration, and nature of repeated high-intensity exercise involving three or more sprints, and/or tackles, and/or scrum, ruck or maul activities within a 21 s period in the 2008 and 2009 Super 14 rugby union season revealed the most intense periods of play were likely to exceed 120 s in duration with as little as 25 s recovery separating consecutive repeated-effort bouts [14]. There were significant variations in the frequency, duration, and nature of repeated high-intensity exercise efforts between positional groups. The number of repeated bouts in a single match ranged from 2 for outside backs to 21 for back-row forwards. Front- and back-row forwards, fly-halves and centres averaged one repeated high-intensity activity bout every 6 min, while outside backs averaged one bout every 10 min. The duration of the single longest repeated high-intensity exercise bouts ranged from 53 s for an outside back to 165 s for a back-row forward. The minimum recovery period between repeated bouts ranged from 25 s for a back-row forward to 64 s for front-row forwards.

**Tactical player substitutions**

One aspect of modern rugby union and rugby sevens competition that has received little attention is tactical player substitutions. Since changes to the laws of the game in 1996 allowing the substitution of players for tactical purposes at the coach’s prerogative, there has
been a substantial decrease in the mean time each player spends on the field and a concomitant increase in the number of players contesting each rugby union match [205]. In 90 international rugby union matches played by the New Zealand national team and their opponents between 2004 and 2010, hookers were the most frequently, and openside flankers the least frequently, substituted forwards (40%, 33 to 49%; rate difference, 90% confidence interval) [207]. In the backs, scrum-half was the most frequently substituted position, and left wing the least substituted (60%, 53 to 67%). Although there is variability between positions, most substitute players contest approximately 21 min of a rugby union match [207]. The dearth of research investigating the effects of player substitutions in rugby union and rugby sevens is surprising given the intense nature of matches likely to result in fatigue that impacts performance, and observations of differences in work-rates of starting and substitute players in other field-based team sports [43,181].

**Frequency and magnitude of impacts**

The recent allowance of wearable micro-sensors incorporating accelerometers during competition has facilitated the quantification of the number and intensity of impacts experienced by players. The sensitivity of this technology allows the measurement of all impacts performed by the player above a specified threshold. As such, the results of this measurement should be interpreted with caution as the number of impacts does not necessarily equate to the number of collisions with the ground or opposing players, but may also incorporate heavy foot-strike impacts and changes of direction while running [104]. Nevertheless, the measurement of impacts provides important information for coaches and support staff of the mechanical load on players during training and competition.

The number of impacts measured during a rugby sevens or rugby union match is proportional to the magnitude of impacts (Table 2.2). As expected based on their positional roles, forwards experience more impacts than backs in rugby union, but the differences in impacts between backs and forwards are unclear in rugby sevens players [239]. Data from a larger sample of players are required to confirm the magnitude of positional differences and their application to the development of position-specific physical preparation programmes. A study of under-19 rugby union players found back-row forwards had the highest number of total impacts during matches, and outside backs the least [265]. However, fly-halves and centres experienced the highest number of severe impacts (>10 g) and front-row forwards the least. Additional data are required to more clearly define differences in the number and magnitude of impacts on players at different levels of competition.
### Table 2.2. Number and magnitude of impacts in rugby sevens and professional rugby union matches; mean ± SD.

<table>
<thead>
<tr>
<th>Source</th>
<th>Level</th>
<th>Position (# of players)</th>
<th>Light (5 to 5.9 g)</th>
<th>Light to moderate (6 to 6.4 g)</th>
<th>Moderate to heavy (6.5 to 6.9 g)</th>
<th>Heavy (7 to 7.9 g)</th>
<th>Very heavy (8 to 10 g)</th>
<th>Severe (&gt;10 g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suarez-Arrones et al, 2013 [239]</td>
<td>Club-level rugby sevens</td>
<td>Forwards (n = 12)</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>13 ± 10; 14 ± 9*</td>
<td>9 ± 5; 7 ± 4*</td>
<td>1 ± 1; 1 ± 1*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Backs (n = 11)</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>13 ± 8; 12 ± 6*</td>
<td>8 ± 6; 7 ± 4*</td>
<td>1 ± 1; 2 ± 2*</td>
</tr>
<tr>
<td>Coughlan et al, 2011 [54]</td>
<td>International-level rugby union</td>
<td>Forward (n = 1)</td>
<td>472</td>
<td>132</td>
<td>66</td>
<td>105</td>
<td>53</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Back (n = 1)</td>
<td>353</td>
<td>65</td>
<td>48</td>
<td>54</td>
<td>40</td>
<td>13</td>
</tr>
<tr>
<td>Cunniffe et al, 2009 [68]</td>
<td>Professional provincial rugby union</td>
<td>Forward (n = 1)</td>
<td>563</td>
<td>398</td>
<td>143</td>
<td>101</td>
<td>56</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Back (n = 1)</td>
<td>349</td>
<td>328</td>
<td>55</td>
<td>38</td>
<td>24</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Backs (n = 7)</td>
<td>382 ± 129</td>
<td>326 ± 173</td>
<td>54 ± 29</td>
<td>30 ± 9</td>
<td>35 ± 26</td>
<td>6 ± 4</td>
</tr>
</tbody>
</table>

NR = not reported; *Values are for first half and second half, respectively.
The measurement of impacts by accelerometer confirms the trend of contacts quantified in professional provincial rugby union matches by notational analysis [256]. Although the methodological differences lead to a lower total number of impacts for the entire team when quantified by notational analysis (386, 307 to 535; mean, range), forwards were still involved in more impacts than backs. The most frequent type of impact for the entire team was contact with the ground (108, 70 to 133). Positional differences in the frequency and magnitude of impacts during rugby union matches are the result of greater involvement of forwards in contact situations with the ball and in competing for the ball. Preliminary notational analysis of club-level rugby sevens matches demonstrated that while the number of rucks contested was similar between positional groups, forwards made a substantially larger number of tackles or tackle attempts than backs (7.4 ± 1.8 vs. 4.1 ± 2.4) [239].

The positional differences in contact-related activity may partially explain the higher bone mineral density and bone mass in rugby union forwards than backs [90]. Rugby union players have enhanced axial and appendicular skeletal mass and increased bone turnover relative to age- and ethnicity-matched controls as a consequence of adaptation to the bone deformations due to vibration and strain induced by muscle contractions and a high frequency of impacts [90]. An understanding of the mechanical stress elicited by impacts can assist coaches and support staff in structuring the volume and intensity of position-specific training and recovery. These findings also highlight the importance of implementing a monitoring system to quantify the contact demands of training and competition.

**Differences between levels of competition**

Only one study has explored differences in movement patterns between club-level and professional rugby union competition. Although clear differences were present between backs and forwards, there were minimal differences in activities of players between club-level competition in New Zealand and professional Super 12 matches assessed with time-motion analyses [72]. Super Rugby is the premier provincial rugby union competition in the southern hemisphere. The Super 12 was contested between 1996 and 2005 before the expansion of the Super Rugby competition. No significant differences were observed between the activities of forwards in Super 12 matches and first division club matches. In contrast, compared with club-level backs, Super 12 backs performed fewer work efforts (defined as cruising, sprinting, tackling, jumping, rucking, mauling, and scrummaging) per match (55 ± 11 vs. 47 ± 9, respectively), had a longer mean rest (inactive, walking, jogging, or lateral or backwards shuffling) period between work bouts (78.0 ± 3.5 s vs. 99.5 ± 3.5 s,
respectively), and spent greater time in utility movements (2.3 ± 1.0% vs. 3.7 ± 2.0%, respectively). No significant differences were observed between competition levels for total work duration (forwards ~10 and backs ~4 min per match). The utility of the previous comparison between club-level and professional matches for contemporary competition is questionable, given the observed increase from 2001 and 2002 to 2008 and 2009 in high-intensity activity, sprint frequency, and work-to-rest ratio for all playing positions in Super Rugby [13].

Although methodological differences may confound direct comparisons of movement patterns observed during professional and international rugby union, international competition appears to be played at a higher intensity than lower-level professional competition [207]. The increase in intensity is represented by a greater distance travelled at higher velocities and a corresponding reduction in the distance covered at lower velocities during international matches. Analyses of the movements of all players from both teams during 27 international matches revealed players typically ran (>4 m·s⁻¹) between 107 and 249 m further per match than reported for one team of professional players during six professional matches [84,207]. The same analyses of international competition showed players travelled between 220 m (for tight forwards) and 570 m (for fly-halves and centres) further per match at high-intensity or maximal velocity (>5 m·s⁻¹) than professional English Premiership players [220].

The differences in technical requirements between varying levels of competition require further analysis [266]. As with movement patterns, differences in the technical performance profiles of players vary by position. Variation in the frequency of scrums, line-outs, tackles, rucks, and mauls in international and professional domestic matches likely represent both modified physical and technical demands between the different levels of competition, as well as differences in the tactics and playing styles adopted by teams competing in different competitions. No published research has examined the differences in movement patterns or technical actions between domestic or club-level and international rugby sevens competition.

**Physiological Responses to Competition**

In conjunction with movement analysis, a variety of physiological parameters have been measured to gauge the physical and metabolic demands of rugby union competition in the professional era. Recent investigations have assessed haematological and biochemical indices [18,114], such as changes in immune system function, metabolic disturbances, markers of
muscle damage and inflammation [2,19,67,111,171,180,236,243-245], antioxidant status and oxidative stress [93], and endocrine status [89,173], to establish the physiological responses to competition. These, and other studies that have examined cardiovascular responses [68,74,237,242] and fluid balance shifts [176,177] during competition, provide coaches and support staff with valuable information on the physiology of the modern rugby player. This knowledge can be applied to optimise the specific physical preparation of players for competition and develop strategies that facilitate recovery and minimise the risk of injury or overtraining.

**Cardiovascular responses**

Reports on heart rate information of rugby players during competition is limited, especially for top-level players, potentially resulting from the logistical issues of taking accurate measurements in a high-intensity collision sport without additional discomfort to the athlete. Despite the acknowledged limitation that the use of heart rate measurements may be inappropriate to assess intense, intermittent activity [167], the analysis of cardiovascular responses may be used to estimate the work output during competition and training as a function of the linear relationship between sub-maximal work rate and heart rate [1]. Customarily, heart rate data have been analysed by the relative time spent within standardised intensity zones defined as a percentage of a player’s predetermined maximum [68,74,242].

A study of 24 under-19 rugby union players reported higher physiological stress in forwards than backs, with forwards competing up to 20% of match time above 95% of their maximum competition heart rate [74]. Forwards spent approximately 72% of the match at a heart rate exceeding 85% of their maximum, whereas the backs spent a significantly larger proportion of match time under 85% of their maximum (approximately 52 to 59%). These positional differences were confirmed in a case study of a fly-half and back-row forward during one professional UK team trial match [68]. In this match, the forward completed a larger proportion of the match at >95% of maximum heart rate (15 vs. 5%), while the back spent more time at a heart rate between 80 to 90% of maximum (28 vs. 42%). Throughout the match, players averaged heart rates of approximately 85% of maximum.

Club-level rugby sevens players spent over 75% of matches with a heart rate exceeding 80% of their predetermined maximum [239,241]. Players spent most match time between 81 and 90% of their maximum heart rate [239,241] and recorded peak values of 92 ± 4% of predetermined maximum in one study [115], and 99 ± 2% in another [241]. Mean heart rates
were similar for backs (86 ± 3% maximum heart rate) and forwards (86 ± 4% maximum heart rate) [239]. One study showed a small increase for both groups in mean heart rate from the first to second half, with backs spending a greater proportion of the second half at 91 to 95% of maximum heart rate [239]. In contrast, two other studies showed no significant differences in mean heart rate between match halves [115, 241].

Recently, the validity of analysing heart rate data using standardised intensity zones has been criticised due to potential errors in the estimates of exercise intensity and energy system contributions as a result of individual differences in fitness levels, the degree of between-player variability in exercise economy, and the somewhat arbitrary selection of intensity thresholds based on maximum heart rate for all players [1, 136]. In an attempt to overcome these limitations, a study of 21 university-level rugby union players classified heart rate data into low-, moderate-, and high-intensity zones based on values corresponding to the first and second ventilatory thresholds of each player [237]. Using this approach, substantially more time was categorised in the high-intensity zone than by analysis using other match analysis methods (mean = 44% of total match time). The mean duration of high-intensity bouts was 77 ± 100 s (mean ± SD), interspersed with periods of low- and moderate-intensity activity of 29 ± 23 and 29 ± 15 s, respectively. Differences in heart rate responses between positional groups were not examined.

Despite the potential influence of factors other than oxygen uptake, such as environmental conditions, hydration status, psychological state, and muscle activation, affecting heart rate response, collectively, measurements of movement patterns and cardiovascular system responses suggest a large contribution from anaerobic energy pathways to support frequent bouts of high-intensity activity. Given the intermittent nature of match activity and the positional differences between backs and forwards, it appears there may be different anaerobic and aerobic system demands for varying positions, at least in rugby union.

**Blood lactate accumulation**

Blood lactate concentration is commonly used as an indicator of exercise intensity by signifying the magnitude of anaerobic glycolytic pathway contribution to adenosine triphosphate (ATP) production in the myocyte [267]. There are currently no published reports of blood lactate measurements in top-level players since rugby union became professional in 1995 and only one published report of domestic-level rugby sevens players [115]. There are several limitations acknowledged with the measurement and interpretation of blood lactate
values during a match. Within competition, the collection of blood lactate data is limited to stoppages in play, such as during injury times and the periods directly following points being scored. In this regard, the timing of blood lactate sampling may not represent the most intense periods of play. Since blood lactate is metabolised during periods of low-intensity activity, the concentration values reported in Table 2.3 represent only the most recent activity performed by players and likely underestimate true peak values. The rate of blood lactate clearance is positively correlated with a player’s aerobic capacity [71]. This relationship suggests a higher aerobic capacity may enhance recovery from high-intensity, lactate-producing exercise. Consequently, professional players playing at higher levels of competition may exhibit different blood lactate profiles from amateur and sub-elite players.

Table 2.3. Blood lactate concentration of rugby union and rugby sevens players during competition.

<table>
<thead>
<tr>
<th>Source/Year</th>
<th>Level</th>
<th>Methods</th>
<th>Position</th>
<th>Blood lactate concentration (mmol·L⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alvear-Ordenes et al, 2005 [2] (n = 15)</td>
<td>Amateur junior and senior rugby union</td>
<td>Venous blood sampled at match completion.</td>
<td>NR</td>
<td>5.9 ± NR NR</td>
</tr>
<tr>
<td>Deutsch et al, 1998 [74] (n = 24)</td>
<td>Amateur under-19 rugby union</td>
<td>Capillary blood sampled during major stoppages of play and half- and full-time.</td>
<td>Forwards Backs</td>
<td>6.6 ± NR 5.1 ± NR 8.5 6.5</td>
</tr>
<tr>
<td>Minett et al, 2010 [180] (n = 12)</td>
<td>Amateur under-19 (n = 4), second grade (n = 4), and first grade (n = 4) rugby union</td>
<td>Capillary blood sampled within 5 min of match completion and analysed within 20 min.</td>
<td>NR</td>
<td>6.2 ± 2.6 6.3 ± 2.2 NR</td>
</tr>
<tr>
<td>Takarada, 2003 [245] (n = 14)</td>
<td>Amateur senior rugby union</td>
<td>Venous blood sampled “immediately” after match completion.</td>
<td>All</td>
<td>3.3 ± NR NR</td>
</tr>
<tr>
<td>Granatelli et al, 2013 [115] (n = 4)</td>
<td>Domestic-level rugby sevens</td>
<td>Capillary blood sampled within 2 min of the end of the first and second half.</td>
<td>NR</td>
<td>8.7 ± 1.7 (1st half) 11.2 ± 1.4 (2nd half) NR</td>
</tr>
</tbody>
</table>

NR = not reported.
When information on blood lactate accumulation is combined with the information provided by time-motion analyses and heart rate responses during rugby union and rugby sevens competition, it appears there is a high reliance on anaerobic energy systems, both alactic and glycolytic, to perform high-intensity activity. However, development of the aerobic system should not be neglected, as oxidative phosphorylation is increasingly utilised during repeated high-intensity efforts with limited recovery [112]. Aerobic metabolism also facilitates resynthesis of creatine phosphate stores during longer periods of reduced-intensity activity.

**Muscle damage**

Elevated concentrations of muscle proteins and enzymes in the blood are indicative of exercise-induced muscle damage [251,252]. Although other biomarkers are often reported, such as myoglobin, glutamate oxaloacetate transaminase, glutamate pyruvate transaminase, and lactate dehydrogenase, changes in creatine kinase concentration are most frequently measured to indirectly indicate the magnitude of muscle damage. Both endogenous and exogenous mechanisms are associated with muscle damage in multiple-sprints sports with body contact. Intermittent high-intensity running typical of rugby matches results in a significant increase in muscle damage and soreness, particularly from the eccentric loading phase of muscle contraction [251]. Rugby union and rugby sevens matches are also characterised by frequent heavy-load collisions. Increases in markers of muscle damage are evident from repeated, direct muscle trauma from impacts with other players and with the ground. Elevations in creatine kinase concentration observed after rugby union matches are summarised in Table 2.4.
<table>
<thead>
<tr>
<th>Source (n of players)</th>
<th>Level</th>
<th>Methods</th>
<th>Time of peak value</th>
<th>Creatine kinase concentration (IU·L⁻¹)</th>
<th>Mean increase from pre-match to peak concentration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alvear-Ordenes et al, 2005 [2] (n = 15)</td>
<td>Amateur junior and senior</td>
<td>Venous blood sampled before and immediately, 24, 48, and 72 h after the match.</td>
<td>Pre-match Mean ± SD Peak Mean ± SD</td>
<td>~140 ± NR ~360 ± NR</td>
<td>24 h after match ~257</td>
</tr>
<tr>
<td>Banfi et al, 2007* [19] (n = 30)</td>
<td>International</td>
<td>Venous blood sampled prior to training, immediately after training and after 20 min of passive or active and cold-water immersion recovery.</td>
<td></td>
<td>339 ± NR 1077 ± NR</td>
<td>318</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>248 ± NR 1240 ± NR</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>310 ± NR 1230 ± NR</td>
<td>397</td>
</tr>
<tr>
<td>Cunniffe et al, 2010 [67] (n = 10)</td>
<td>International</td>
<td>Venous blood sampled the morning of the match, within 15 min of match completion, and 14 and 38 h after the match.</td>
<td></td>
<td>333 ± 155 1182 ± 730</td>
<td>355</td>
</tr>
<tr>
<td>Gill et al, 2006 [111] (n = 23)</td>
<td>Professional provincial</td>
<td>Transdermal exudate sampled 3.5 h before, immediately, 36 and 84 h after match completion.</td>
<td></td>
<td>1023 ± 308 2194 ± 834</td>
<td>214</td>
</tr>
<tr>
<td>Mashiko et al, 2004 [171]</td>
<td>University</td>
<td>Venous blood sampled in the morning before, and after a match.</td>
<td></td>
<td>832 ± 812 966 ± 865</td>
<td>116</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>562 ± 389 676 ± 437</td>
<td>120</td>
</tr>
<tr>
<td>Minetti et al, 2010 [180] (n = 8)</td>
<td>Amateur under-19, second grade, and first grade</td>
<td>Venous blood sampled 3 h before and 24 h after the match.</td>
<td></td>
<td>276 ± 105 645 ± 123</td>
<td>234</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>290 ± 164 882 ± 472</td>
<td>304</td>
</tr>
<tr>
<td>Smart et al, 2008 [236]</td>
<td>Professional provincial</td>
<td>Transdermal exudate sampled ~210 min before and within 30 min after match completion.</td>
<td></td>
<td>NR NR</td>
<td>Immediately after match 1440 ± 677** 545 ± 341**</td>
</tr>
<tr>
<td></td>
<td>Forwards (n = 12)</td>
<td></td>
<td>Backs (n = 11)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suzuki et al, 2004 [243] (n = 15)</td>
<td>University</td>
<td>Venous blood sampled the morning of the match, within 10 min of match completion, and in the mornings 1 and 2 days after the match following active or passive recovery.</td>
<td></td>
<td>414 ± 429 637 ± 543</td>
<td>154</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>352 ± 132 715 ± 438</td>
<td>203</td>
</tr>
<tr>
<td>Takarada, 2003 [245] (n = 14)</td>
<td>Amateur senior</td>
<td>Venous blood sampled 48 h before, and immediately, 45 and 90 min, and 24, 48, 72 h after the match.</td>
<td></td>
<td>NR 1081 ± 595</td>
<td>24 h after match -</td>
</tr>
</tbody>
</table>

IU = international units; NR = not reported; *Measured following a training session, not a match; **Δ creatine kinase concentration (IU·L⁻¹).
To date, only one study has investigated changes in markers of muscle damage in rugby sevens players [244]. This study observed seven members of the Japanese national team before and after two matches played on the same day with approximately 4 hours between matches. Compared with the baseline serum creatine kinase concentration measurement (359 ± 131 IU·L⁻¹), significantly higher concentrations were reported prior to (424 ± 140 IU·L⁻¹), and then after (509 ± 184 IU·L⁻¹), the second match of the day. The ~27% elevation in creatine kinase concentration from after the first to after the second match indicates a cumulative effect of match activity. The cumulative rise in creatine kinase values even after only a short exposure to match time is an important consideration for coaches and support staff working with rugby sevens players, especially given these players may be required to compete in up to six matches in 2 days. Indeed, following a rugby union match, creatine kinase concentration may be elevated above pre-match values for up to 48 hours [2,245]. Sustained elevated measures of muscle damage and soreness and the associated decrements in function and performance indicate the need to implement sport-specific recovery strategies for seasonal rugby union competition and tournament-style rugby sevens competition [111].

Regardless of the stage of competitive season, 87% of creatine kinase concentration measurements from a squad of professional rugby union players in France were higher than the normal reference interval [114]. Observations of consistently elevated creatine kinase concentrations in rugby union players and other sports have led to the suggestion that higher resting creatine kinase values in athletes compared with non-athletes may require sport-specific reference ranges [114]. Higher upper-limit reference ranges may be required for athletes given their greater muscle mass and frequent training. Sport-specific reference values would reduce the likelihood of physicians misdiagnosing high creatine kinase concentrations as pathological and assist coaches in prescribing appropriate training and recovery.

The degree of muscle damage experienced during exercise is related to both the intensity and duration of activity, with intensity having the greatest effect [252]. The one- to five-fold increases in creatine kinase concentration following rugby union competition are related to match time \((r = 0.69\) to \(0.82\))\), time defending \((r = 0.72\) to \(0.74\))\), number of tackles \((r = 0.86\) to \(0.92\))\), very high-intensity running distance covered in the second half \((>5.56 \text{ m·s}^{-1}, r = -0.76\))\), and total number of contact events \(r = 0.71\) to \(0.78\)\) [67,180,236,245]. In backs, large correlations were also observed between creatine kinase changes and the number of hit-ups \(r = 0.74\)\)\), and number of occasions the player was among one of the first three players to join a ruck or maul in attack \(r = 0.79\) [236]. In forwards, pre- to post-match changes in creatine
kinase concentration were also associated with the number of scrums performed \((r = 0.73)\) [236]. The increase in creatine kinase concentration following a rugby union match is reportedly higher for forwards than backs [236]. This difference is likely the result of the differing roles of backs and forwards and higher frequency of tasks involving collisions performed by forwards [236].

In some instances, severe muscle damage results in trauma graded as an injury [245]. In one documented case of a player that withdrew from competition 15 min into the second half due to bruising on the thigh resulting from being tackled, creatine kinase concentration was substantially higher than the team mean 24 hours after the match \((2621 \text{ vs. } 1081 \pm 595 \text{ IU·L}^{-1}; \text{mean ± SD})\) [245]. Tackles are the most common form of contact in rugby union and also result in the most injuries [95]. However, scrums and collisions present the highest risk of injury per event [95]. The high-intensity contact nature of international rugby union carries a relatively high injury risk [97]. Interestingly though, the magnitude of injury risk is greater in international-level rugby sevens than rugby union despite differences in anthropometric characteristics of players and lower emphasis on physical confrontation [98]. Although the reasons for a greater injury risk in rugby sevens are unknown, it is possible the fast nature of rugby sevens increases the energy transfer during contact events, increasing the probability of serious injury. The open style of rugby sevens may also explain the higher proportion of severe knee and ankle ligament injuries relative to observations during the 2007 Rugby World Cup resulting from more frequent evasive running, turning, and cutting manoeuvres.

**Physical Characteristics and Capacities of Rugby Players**

Public release of information on the characteristics and capacities of rugby players in the professional era is limited by the competitiveness between teams. Laboratory- and field-based testing data complements the information gained from match analyses. Anthropometric, physiological, and performance testing in the laboratory and the field assists coaches and support staff in monitoring long- and short-term training adaptations, prescribing and assessing individualised physical preparation programmes, identifying talented players, selecting players, and predicting performance outcomes. Although recommendations for the assessment of rugby players have been developed to investigate players’ physiological characteristics and components of fitness [135], the lack of standardisation of testing procedures can make comparisons of findings between studies difficult.
Elite rugby union players are characterised by the heterogeneity of their physical and physiological attributes [78]. Unlike many other team sport athletes, rugby union players frequently have distinct physiques that predispose their suitability to a particular playing position. The diverse range of physical characteristics and capacities observed in rugby players is dictated by the contrasting physical and technical roles of each position.

**Body Mass**

There has been a progressive increase in the body mass and height of top-level rugby union players in the past 30 to 40 years [193,205,228]. This increase has accelerated since the introduction of professionalism in 1995 as a result of selection pressures, changes in match activity profiles and physical demands, and increased attention to weight training and nutrition. A higher body mass is associated with greater force production in the rugby union scrum [208] and competitive success [193,228].

A greater body mass allows a player to generate a higher momentum which is advantageous in contact situations. This fact at least partially explains the well-established higher body mass of forwards than backs (Figure 2.1). Substantial differences in body mass are evident between the distinct sub-groups of player positions relating to the positional role. For example, in the 2011 Rugby World Cup, the tight five forwards (front row, 113.3 ± 7.9 kg; second row, 114.2 ± 6.1 kg; mean ± SD) were heavier than the back-row forwards (107.3 ± 5.7 kg), who were heavier than backs (92.8 ± 8.2 kg) [97]. Within the backs, halves were the lightest (87.8 ± 6.7 kg) and centres the heaviest (97.2 ± 6.9 kg).
There is a dearth of information on the anthropometry of rugby sevens players. The limited number of studies published between 1999 and 2013 reported the body mass and height of international- and club-level players. On average, rugby sevens backs that competed in the 2008/2009 IRB Sevens World Series and Rugby World Cup Sevens 2009 were ~6.8 kg lighter than rugby union backs that competed in the 2011 Rugby World Cup, while rugby sevens forwards were 13.8 kg lighter than their international rugby union counterparts (Table 2.5). These differences reflect the substantially different movement, contact, and activity patterns between the two formats. There are also substantial differences in the ages of players competing internationally in rugby union and rugby sevens (Table 2.5). Traditionally, many teams select talented young players to compete in rugby sevens as a development pathway in their careers. Given the historical changes observed in the characteristics of rugby union players [193,205,228], it is likely there have been parallel changes in the physical and physiological attributes of rugby sevens players. The potential changes in characteristics of players selected for international tournaments, corresponding with the increased exposure and professionalism of rugby sevens, have yet to be scientifically investigated.
Table 2.5. Body mass of international rugby union and rugby sevens players; mean ± SD.

<table>
<thead>
<tr>
<th></th>
<th>Backs</th>
<th>Forwards</th>
<th>All players</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rugby union [97] (n)</td>
<td>281</td>
<td>334</td>
<td>615</td>
</tr>
<tr>
<td>Age (years)</td>
<td>26.7 ± 3.5</td>
<td>27.9 ± 3.5</td>
<td>27.4 ± 3.6</td>
</tr>
<tr>
<td>Body Mass (kg)</td>
<td>92.8 ± 8.2</td>
<td>111.5 ± 7.4</td>
<td>102.9 ± 12.1</td>
</tr>
<tr>
<td>Rugby sevens [98] (n)</td>
<td>162</td>
<td>88</td>
<td>264*</td>
</tr>
<tr>
<td>Age (years)</td>
<td>22.8 ± 3.1</td>
<td>23.8 ± 2.9</td>
<td>23.1 ± 3.1</td>
</tr>
<tr>
<td>Body Mass (kg)</td>
<td>86.0 ± 7.8</td>
<td>97.7 ± 7.2</td>
<td>90.1 ± 9.5</td>
</tr>
</tbody>
</table>

*14 players did not identify a playing position.

Differences in body mass between different playing levels have been documented previously [78]. Briefly, body mass generally increases as playing level progresses. Furthermore, there is an association between body mass and final ranking in Rugby World Cup competition, with a higher mean body mass being related to further progress in the tournament [193,228]. Mean body mass (rho = -0.49) and mean height (rho = -0.59) were correlated with final ranking of the 20 finalist squads of the 1999 Rugby World Cup [193].

**Height**

Similar to body mass, there is an increase in height in rugby union players with progressing levels of competition [78]. There is also a positive association between mean team height and final ranking in Rugby World Cup tournaments, with teams with taller players performing better [193]. While players are becoming larger from one Rugby World Cup to the next, teams with heavier forwards and taller backs perform better than others [228]. The distinct positional demands of rugby produce marked differences in the height of backs and forwards (Figure 2.2). Within the forwards of the 2011 Rugby World Cup, players in the second row were the tallest (1.98 ± 0.03 m) [97]. Greater height for lock forwards is advantageous during the line-out contest, a critical component of rugby union matches. The ball is typically caught 3 to 3.5 m off the ground during line-out throws [222]. A greater height allows players a superior absolute jump or lifting height in the line-out. Of the remaining forwards, the back-row players (1.90 ± 0.04 m) are taller than the front-row positions (1.84 ± 0.04 m) [97]. Differences in height amongst the backs are less pronounced than in the forwards, although on average, the halves are shortest (1.79 ± 0.06 m) [97].
International rugby sevens backs and forwards are shorter than international rugby union players (Figure 2.2, Table 2.6). However, the relative difference in height (~2%) between players of the two rugby formats is smaller than the difference in body mass (~12%). The difference in height between backs and forwards appears similar in rugby union and rugby sevens.

Table 2.6. Height of international rugby union and rugby sevens players; mean ± SD.

<table>
<thead>
<tr>
<th></th>
<th>Backs</th>
<th>Forwards</th>
<th>All players</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rugby union [97] (n)</td>
<td>281</td>
<td>334</td>
<td>615</td>
</tr>
<tr>
<td>Age (years)</td>
<td>26.7 ± 3.5</td>
<td>27.9 ± 3.5</td>
<td>27.4 ± 3.6</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>182.7 ± 5.9</td>
<td>189.2 ± 7.0</td>
<td>186.2 ± 7.3</td>
</tr>
<tr>
<td>Rugby sevens [98] (n)</td>
<td>162</td>
<td>88</td>
<td>264*</td>
</tr>
<tr>
<td>Age (years)</td>
<td>22.8 ± 3.1</td>
<td>23.8 ± 2.9</td>
<td>23.1 ± 3.1</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>180.1 ± 6.4</td>
<td>187.5 ± 5.8</td>
<td>182.5 ± 7.1</td>
</tr>
</tbody>
</table>

*14 players did not identify a playing position.
**Body Composition**

Modern rugby players strive to increase their body mass to gain a competitive advantage. However, when this additional mass is fat rather than lean mass a player’s power-to-weight ratio and ability to accelerate are reduced, and energy expenditure during activity is increased [81]. Excess body fat also has negative implications for thermoregulation [129,230]. Conversely, the development of lean mass augments strength, power, and speed [27] highlighting the importance of monitoring the body composition of professional players. Although many studies have reported the body-fat levels of rugby union players, the comparison of results is confounded by limitations in calculating percentage of body fat from estimates of body density and subcutaneous skinfold thickness measurements. Variations in measurement error associated with differing methods and prediction equations should be acknowledged when comparing results. Given concerns with the assessment of body composition using doubly-indirect methods, it is now recommended to monitor the body mass and sum of skinfolds thickness of players [135]. The lean mass index, calculated using body mass and sum of seven skinfolds thickness, has been used as a practical empirical measure to assess within-player proportional changes in body mass adjusted for changes in skinfolds thickness [82].

As with body mass and height, forwards have greater relative body-fat levels than backs (Figure 2.3). Forwards also have greater absolute fat and lean mass than backs [27]. Disparity in body composition between backs and forwards is also demonstrated by sum of skinfold measurements and lean mass index (Table 2.7). The positional differences in body composition reflect the differences in competition demands for backs and forwards. Backs have greater acceleration and speed requirements than forwards which explain their lower body-fat levels. In contrast, forwards have greater strength and power requirements to contest possession of the ball, with frequent contact with the opposition. Although additional subcutaneous fat may act as a protective barrier during contact, there is little evidence supporting this assertion [201]. Additional non-functional mass, such as adipose tissue, compromises a player’s sprinting ability, agility, and endurance.
Given the greater relative running volume, increased high-intensity running, and higher work-to-rest ratio of rugby sevens competition compared with rugby union [241], it is unsurprising rugby sevens players have relatively low body-fat levels. Positional differences in physique and body composition in rugby union appear less pronounced in rugby sevens. Successful rugby sevens players of all positions require a high degree of mobility to
accommodate the faster and more open style of play. Simultaneously, the reduced frequency of set-piece plays, such as scrums and line-outs, in rugby sevens matches results in greater homogeneity of anthropometric characteristics among different positions. In club-level rugby sevens players, the mean sum of six skinfolds thickness was $61.6 \pm 6.0$ mm [239,241]. Based on skinfold thickness measurements of 27 players competing in an international rugby sevens tournament in 1996, body fat was estimated to be $12.1 \pm 2.2\%$ for forwards and $11.4 \pm 2.5\%$ for backs [216]. A similar anthropometric analysis of 108 forwards and 138 backs competing in a rugby sevens tournament in Uruguay in 1996 and 1997 reported substantial differences in physique and body composition between forwards and backs [215]. Relative body fat estimated from skinfold measurements was $13.9 \pm 3.7\%$ for forwards and $11.8 \pm 3.2\%$ for backs. Significant differences were also observed between positional groups in estimates of absolute muscle mass, absolute bone mass, and somatotype. However, when these body composition measurements were reported in relative terms, the positional differences were no longer apparent. The measurement of body composition of modern international-standard rugby sevens players has yet to utilise more accurate and finer resolution measurement techniques, such as dual-energy X-ray absorptiometry (DXA). Assessments using methods such as DXA would allow greater insight into the similarities and differences in body composition between rugby sevens and rugby union players.

There is only exiguous information on the body composition of rugby players measured using DXA. The measurement of body composition using DXA allows for the regional distribution of bone mineral, fat, and lean soft tissue mass to be quantified. Rugby union backs have significantly higher relative lean soft tissue mass than forwards in the arms (84 vs. 77%), legs (80 vs. 72%) and trunk (89 vs. 79%) [27]. In contrast, forwards have a higher relative fat mass than backs in the arms (19 vs. 11%), legs (23 vs. 15%), and trunk (18 vs. 8%) [27]. Not only are there substantial differences in the absolute and relative fat and lean soft tissue mass between backs and forwards, but the regional distribution of this tissue across the body also differs between backs and forwards [27]. No studies have examined the regional distribution of tissue in rugby sevens or international-level rugby union players. Studies of elite-level players of both formats would provide valuable information on the differences in body composition and regional tissue distribution between positional groups.

**Aerobic Performance**

Developing a player’s aerobic capacity supports anaerobic energy pathways, assists in fatigue resistance and lactate clearance, and facilitates recovery between bouts of high-intensity
activity [253]. Maximal oxygen uptake (\(\dot{VO}_2\text{max}\)) has been commonly reported as an indicator of aerobic fitness in rugby players. Additional measures of aerobic fitness such as maximal aerobic running speed or velocity at \(\dot{VO}_2\text{max}\) [172], running economy [168], and anaerobic threshold [227, 237] are reported less frequently. These measures are typically used to prescribe and monitor prolonged, steady-state exercise. The relative importance of these measures to performance and training in high-intensity intermittent team sports, such as rugby union and rugby sevens, is currently unclear.

A player’s \(\dot{VO}_2\text{max}\) is commonly measured in the laboratory on a motorised treadmill using an incrementally-graded protocol. The time and financial expense of performing this measurement is often prohibitive for rugby teams during the competition season. As a more practical alternative, other field-based test protocols are often adopted to simplify the assessment of players’ endurance in a team setting. Examples of tests used in rugby union research include the 3000-m time trial [192], incremental track-based running tests [91, 172], and the multi-stage shuttle run [192]. Several of these tests allow the prediction of \(\dot{VO}_2\text{max}\). However, comparisons between test results should be interpreted with caution as the validity of predicted \(\dot{VO}_2\text{max}\) estimates from indirect measures in rugby players is unclear. Indeed, the multi-stage shuttle run scores of a small group of international rugby union players \((n = 7)\) had a poor relationship with \(\dot{VO}_2\text{max}\) measured in the laboratory [192].

The \(\dot{VO}_2\text{max}\) of rugby union forwards is in excess of 5 L·min\(^{-1}\) [269]. A well-developed capacity of forwards to produce very high aerobic power output is required to sustain repeated high-intensity bouts of rucking, mauling, scrummaging, and running with the ball and in support. Table 2.8 shows that when \(\dot{VO}_2\text{max}\) is expressed in absolute units, the forwards have greater aerobic capacity than backs. However, when \(\dot{VO}_2\text{max}\) is expressed relative to body mass, the values favour backs. Although body mass should be considered when interpreting aerobic capacity in relation to activities such as running, there is potential for a larger body mass to bias the reporting of \(\dot{VO}_2\text{max}\) using ratio scaling (i.e., per kg of body mass). Given the variation in body mass of rugby players, alternate methods of reporting results, such as using allometric scaling, have been proposed to allow more valid comparisons between individuals [186]. No published studies have reported the \(\dot{VO}_2\text{max}\) of professional rugby players using alternate scaling or normalising methods.
Table 2.8. Absolute and relative maximal oxygen uptake (\(\dot{V}O_2\text{max}\)) or peak oxygen uptake (\(\dot{V}O_2\text{peak}\)) of professional rugby union players; mean ± SD.

<table>
<thead>
<tr>
<th>Source</th>
<th>Level</th>
<th>(\dot{V}O_2\text{max}/\dot{V}O_2\text{peak} (L·min(^{-1})))</th>
<th>(\dot{V}O_2\text{max}/\dot{V}O_2\text{peak} (mL·kg(^{-1})·min(^{-1})))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predicted (incremental running test)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elloumi et al, 2008 [91]</td>
<td>International (n = 20)</td>
<td>5.3*</td>
<td>58.0 ± 3.1</td>
</tr>
<tr>
<td>Maso et al, 2002 [172]</td>
<td></td>
<td>5.8* 5.3*</td>
<td>54.8 ± 4.5 61.1 ± 2.3</td>
</tr>
<tr>
<td>Forwards (n = 10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backs (n = 10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treadmill</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cunniffe et al, 2009 [68]</td>
<td>Professional provincial (n = 3)</td>
<td>5.6*</td>
<td>53.3 ± 2.1</td>
</tr>
<tr>
<td>Lombard, 2003 [168]</td>
<td>National (n = 7)</td>
<td>4.9* 4.6*</td>
<td>48.3 ± 3.5 55.2 ± 5.5</td>
</tr>
<tr>
<td>Forwards (n = 10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backs (n = 6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O’Gorman et al, 2000 [192]</td>
<td>International (n = 7)</td>
<td>5.1*</td>
<td>54.1 ± 3.7</td>
</tr>
<tr>
<td>Scott et al, 2003 [227]</td>
<td>Professional provincial (n = 13)</td>
<td>4.3* 4.2*</td>
<td>41.2 ± 9.7 48.3 ± 8.3</td>
</tr>
<tr>
<td>Forwards (n = 15)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backs (n = 10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warrington et al, 2001 [269]</td>
<td>International (n = 20)</td>
<td>5.3 ± 0.5</td>
<td>51.1 ± 6.3</td>
</tr>
<tr>
<td>Unspecified protocol</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cunniffe et al, 2010 [67]</td>
<td>International (n = 10)</td>
<td>5.5*</td>
<td>53.2 ± 3.5</td>
</tr>
<tr>
<td>Cunniffe et al, 2011 [66]</td>
<td>Professional provincial (n = 16)</td>
<td>5.6* 5.0*</td>
<td>50.4 ± 5.2 55.2 ± 5.2</td>
</tr>
<tr>
<td>Forwards (n = 16)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backs (n = 14)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finaud et al, 2006 [93]</td>
<td>Professional provincial (n = 17)</td>
<td>5.6*</td>
<td>59.1 ± 3.3</td>
</tr>
</tbody>
</table>

*Estimated based on reported mean body mass.
Although improving a rugby player’s VO₂max is likely to positively influence performance, it does not appear to be the most important fitness characteristic in a player’s profile. This contention is supported by the lower relative VO₂max of rugby union players compared with athletes competing in other field-based team sports with a reduced emphasis on physical contact and greater running volume, such as field hockey (61.8 ± 1.8 mL·kg⁻¹·min⁻¹) [36] and soccer (63.2 ± 4.9 mL·kg⁻¹·min⁻¹) [69]. Interestingly, despite the relatively greater volume of running in rugby sevens compared with rugby union, the relative VO₂max of club-level rugby sevens players (mean = ~52 to 56 mL·kg⁻¹·min⁻¹) [115,239,241] is similar to reports of professional and international rugby union players. Given the moderate aerobic qualities of rugby players relative to endurance-sport athletes and the limited ecological validity of continuous running tests for assessing a player’s aerobic fitness as required for competition, it is increasingly common for coaches and scientists to adopt other test methods that assess a player’s ability to perform repeated high-intensity efforts under maximal activation of the aerobic system. Tests such as the Yo-Yo intermittent recovery tests evaluate the endurance qualities of players under more team-sport-specific conditions, incorporating acceleration, deceleration, and change of direction [20]. As the Yo-Yo test reflects the ability to repeatedly perform high-intensity exercise, it concurrently assesses a player’s aerobic output with involvement of anaerobic responses and short-duration recovery. Studies of other sports demonstrate the Yo-Yo test is a more accurate predictor of on-field performance than VO₂max and offers greater sensitivity in discriminating between athletes of different levels and evaluating training interventions [20]. Similarly in rugby union, more mature players tend to outperform junior players and backs outperform forwards in the Yo-Yo intermittent recovery test [135].

**Anaerobic Performance**

Anaerobic capacity and power are important fitness components for rugby union and rugby sevens players during intermittent training and competition activity. Anaerobic metabolism is required for the execution of power-based movements such as tackling, scrummaging, intense accelerations, jumping, and application of force during rucking and mauling. The development of a high anaerobic capacity is also paramount to the ability to sustain and repeat high-intensity activity. Given the importance of anaerobic qualities for rugby performance, it is surprising little research has focused on the anaerobic characteristics of elite-level players. The anaerobic performance of amateur rugby union players was reviewed
over a decade ago [187]. However, there is a paucity of research on the anaerobic characteristics of high-level professional rugby players.

There is no standardised protocol for the assessment of anaerobic characteristics in rugby players. Given the limited ecological validity of laboratory-based measures, such as cycle ergometry, anaerobic metabolic properties are rarely tested in isolation [17,168,250]. Maximal cycle ergometer tests demonstrate higher peak power output in rugby union forwards compared with backs [17,168,250]. This finding is likely the result of the greater absolute muscle mass of forwards than backs, which is advantageous during contests for the ball. Maximal testing in the laboratory indicates players exhibiting the highest peak power values also tend to have the highest rate of fatigue during tests of moderate duration (30 s) [168,250]. This finding implies there may be a compromise between peak anaerobic power and anaerobic capacity. However, it is likely power decrements are associated with the relative contribution of metabolic pathways supporting force production rather than the absolute force generated [108,178]. Although absolute power production is important during activity involving physical contact between players, power output relative to the mass of a player may better reflect running performance. When peak power output is expressed relative to body mass, the results marginally favour the backs over forwards [250].

The questionable relevance to rugby competition and lack of translation to training prescription of laboratory-based testing has lead to the development of more sport-specific tests, such as repeated-sprint ability tests. These tests evaluate players under conditions that more closely replicate the demands of competition [135,172,191,234]. For example, the $6 \times 30$-m repeated-sprint ability test is used to assess players using sprint distances and recovery times similar to those experienced during matches [135]. The rugby-specific repeated-speed test also incorporates standardised work where players jog with a weighted bag and perform dynamic down and ups (that is, the player goes from standing to a prone position on the ground before returning to their feet) during the periods between sprint bouts [234]. Backs generally outperform forwards in repeated-sprint ability tests [135,172]. However, the interpretation of repeated-sprint ability tests is largely dependent upon the method of analysis employed [194,203]. Reports of better repeated-sprint ability in backs to a large extent reflect their superior single sprint performance compared with forwards [203]. The ability of an athlete to perform repeated bouts of high-intensity activity is highly task-dependent [32,112]. Recent research on players’ abilities to perform tasks specific to rugby union found different responses and levels of fatigue produced by a sprinting task, scrummaging task, and mauling
task [182]. It appears differences in psycho-physiological responses to the tasks may be related to different mechanisms of fatigue. Such findings support the development of position-specific tests of repeated-effort ability based on the player’s role [182].

Tests such as the Bath University Rugby Shuttle Test (BURST) have been developed based on time-motion analyses of rugby union matches in an attempt to replicate the physical demands of competition [219]. Such rugby-specific test protocols can be used to assess interventions likely to affect performance [218] and could potentially be used for player conditioning. Although these tests are conducted under controlled conditions, they may be limited in their ability to isolate the specific physiological qualities or mechanisms that underpin performance.

**Muscular Strength and Power**

Muscular strength and power are critical components for success during attack and defence in both rugby formats [135]. A player’s strength and power relative to their body mass are related to acceleration, running velocity, and the ability to quickly change direction [189,233,278]. Absolute strength and power are essential to apply high forces rapidly in contact situations and during scrumming [208]. Strength is the maximal force generated by a muscle or groups of muscles at a specified velocity [159]. The strength of rugby players is usually evaluated using a gym-based assessment of weightlifting exercises. Measurements using this approach allow for results to be transferred directly to resistance training prescription to develop desired qualities. Maximal strength is commonly assessed using variations of the bench press exercise for the upper-body, and the back squat exercise for the lower-body [135]. Less commonly, other exercises are also used, such as the chin-up [63,135,234]. The performance in these exercises is often reported as a one-repetition maximum: the maximum weight lifted for a single repetition. This value can be measured directly or estimated based on the weight lifted for a higher number of repetitions [163].

The physicality of professional rugby union requires high levels of strength for success. Given the benefits of strength in contact situations, rugby union forwards usually possess greater strength than backs in the variations of the bench press (Figure 2.4) and back squat (Figure 2.5). Even in club-level players, the mean force produced by a forward pack during a scrum can be as high as 9090 ± 70 N [208]. These measurements demonstrate the necessity of position- and task-specific strength development. For example, the props and locks, typically the heaviest players on the field, produce the highest individual force during the
scrum (props 1420 ± 320 N, locks 1450 ± 270 N) [208]. In contrast, the loose forwards, who are not exposed to the direct impact force in the scrum collision, produce a lower individual scrumming force (1270 ± 240 N).

Figure 2.4. Compilation of one-repetition maximum bench press performance of professional rugby union players reported between 2006 and 2012 [3-5,8,29,31,56,57,62,63,111,156,234].
Figure 2.5. Compilation of one-repetition maximum back squat performance of professional rugby union players reported between 2007 and 2012 [3-5,7-9,29,30,48,49,56,57,61-63,123,156,157,210,234,271].

Power refers to the rate of performing work and is calculated as the product of force and velocity of movement [159]. Exercises typically chosen to assess the muscular power of rugby players are the weighted and unweighted countermovement jump and weighted and unweighted squat jump for the lower-body, and bench throw for the upper-body [4,5,7-9,29,31,56,59,120,122,123,156,254]. It is recommended coaches and scientists report the peak power output during these exercises as this parameter has the highest association with athletic performance [76].

The mean peak power reported for professional rugby union players varies from 873 to 1197 W for the bench throw (Table 2.9) and 4254 to 8880 W for the countermovement jump (Table 2.10). Studies examining more than a single load have reported peak power in the countermovement jump is achieved with the mass of the player only without the addition of an external load [7,9,29,63,123]. The optimal load for peak power production in the bench throw exercise remains contentious [64]. An external load equivalent to 30% of estimated bench press one-repetition maximum was optimal for peak power output in a group of 47 professional rugby union players [29]. However, the estimated bench press one-repetition maximum for this group (124 ± 19 kg) was relatively low in comparison with other reports of
professional players (Figure 2.4) and the mean peak power (873 ± 24 W) was the lowest of all the published results reviewed (Table 2.9). It is likely several factors contribute to the load at which peak power output is achieved, including the player’s training background and current physical and training status [64]. Longitudinal changes in the power profile of professional rugby players associated with training and the implications for programme prescription warrant further investigation.

Table 2.9. Peak power output during the bench throw of professional rugby union players; mean ± SD.

<table>
<thead>
<tr>
<th>Source</th>
<th>Load at peak power measurement</th>
<th>Peak power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argus et al, 2009 [8]</td>
<td>50 and 60% bench press 1-RM</td>
<td>1150 ± 23%</td>
</tr>
<tr>
<td>(n = 32)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n = 33)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n = 43)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bevan et al, 2009 [31]</td>
<td>40% predicted bench press 1-RM</td>
<td>916 ± 116</td>
</tr>
<tr>
<td>(n = 26)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bevan et al, 2010 [29]</td>
<td>30% predicted bench press 1-RM</td>
<td>873 ± 24</td>
</tr>
<tr>
<td>(n = 47)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crewther et al, 2009 [57]</td>
<td>50 kg</td>
<td>1244 ± 159</td>
</tr>
<tr>
<td>Forwards (n = 18)</td>
<td></td>
<td>1119 ± 161</td>
</tr>
<tr>
<td>Backs (n = 20)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crewther et al, 2009 [62]</td>
<td>50 kg</td>
<td>1287 ± 193</td>
</tr>
<tr>
<td>Forwards (n = 15)</td>
<td></td>
<td>1208 ± 203</td>
</tr>
<tr>
<td>Backs (n = 12)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crewther et al, 2011 [56]</td>
<td>50 kg</td>
<td>1197 ± 191</td>
</tr>
<tr>
<td>(n = 25)</td>
<td></td>
<td>1215 ± 185</td>
</tr>
<tr>
<td>Kilduff et al, 2007 [156]</td>
<td>40% predicted bench press 1-RM</td>
<td>903 ± 145</td>
</tr>
<tr>
<td>(n = 23)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1-RM = one-repetition maximum.
Table 2.10. Peak power output during the countermovement jump of professional rugby union players; mean ± SD.

<table>
<thead>
<tr>
<th>Source (n of players)</th>
<th>Load at peak power measurement</th>
<th>Peak power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argus et al, 2009 [8] (n = 32)</td>
<td>Body mass + 55 and 60% box squat 1-RM</td>
<td>5190 W ± 15%</td>
</tr>
<tr>
<td>Argus et al, 2010 [4] (n = 33)</td>
<td>Body mass + 55 and 60% box squat 1-RM</td>
<td>5360 ± 627</td>
</tr>
<tr>
<td>Argus et al, 2011 [7] (n = 18)</td>
<td>Body mass only</td>
<td>8880 ± 2186</td>
</tr>
<tr>
<td>Argus et al, 2012 [9] (n = 18)</td>
<td>Body mass only</td>
<td>6560 ± 820</td>
</tr>
<tr>
<td>Argus et al, 2012 [5] (n = 43)</td>
<td>Body mass + 55 and 60% box squat 1-RM</td>
<td>5240 ± 670</td>
</tr>
<tr>
<td>Bevan et al, 2010 [29] (n = 36)</td>
<td>Body mass only</td>
<td>4751 ± 529</td>
</tr>
<tr>
<td>Crewther et al, 2011 [63] (n = 30)</td>
<td>Body mass only</td>
<td>6557 ± 897</td>
</tr>
<tr>
<td>Crewther et al, 2012 [60] (n = 16)</td>
<td>Body mass only</td>
<td>5241 ± 581</td>
</tr>
<tr>
<td>Inside backs (n = 12)</td>
<td>5627 ± 648</td>
<td></td>
</tr>
<tr>
<td>Outside backs (n = 12)</td>
<td>5628 ± 704</td>
<td></td>
</tr>
<tr>
<td>Loose forwards (n = 19)</td>
<td>5573 ± 631</td>
<td></td>
</tr>
<tr>
<td>Tight forwards (n = 20)</td>
<td>5240 ± 670</td>
<td></td>
</tr>
<tr>
<td>Crewther et al, 2012 [59] (n = 48)</td>
<td>Body mass only</td>
<td>6533 ± 538</td>
</tr>
<tr>
<td>Hansen et al, 2011 [121] (n = 25)</td>
<td>Body mass + 40 kg</td>
<td>4864 ± 726</td>
</tr>
<tr>
<td>Hansen et al, 2011 [122] (n = 25)</td>
<td>Body mass + 40 kg</td>
<td>4886 ± 749</td>
</tr>
<tr>
<td>Hansen et al, 2011 [123] (n = 18)</td>
<td>Body mass only</td>
<td>4254 ± 549</td>
</tr>
<tr>
<td>Kilduff et al, 2007 [156] (n = 23)</td>
<td>Body mass only</td>
<td>4790 ± 434</td>
</tr>
<tr>
<td>Turner et al, 2012 [254] (n = 11)</td>
<td>Body mass + 20% countermovement jump 1-RM</td>
<td>4716 ± 448</td>
</tr>
</tbody>
</table>

1-RM = one-repetition maximum; *Inside backs includes scrum-half, fly-half, and inside centre.

Positional variation in the absolute muscular power of rugby union players is currently unclear. When a fixed load (50 kg) was used to assess peak power in the bench throw, forwards produced a significantly higher peak power than backs in one study (1244 ± 159 W vs. 1119 ± 161 W) [57], but not another (1287 ± 193 W vs. 1208 ± 203 W) [62]. When peak power values are reported relative to body mass they favour lighter backs over heavier
forwards [57,60]. The bias in reporting strength and power measures may be removed using allometric scaling [57,60,63]. There is a need for further analysis of the peak force and peak velocity values of backs and forwards. It is plausible players of different positions produce high peak power values through the dominance of strength or speed qualities related to their training and roles during competition. Without further investigation it is unclear whether forwards generate peak power through higher force production from superior strength and body mass, or if backs achieve peak power through a greater velocity of movement. Empirical evidence of the relationship between these factors, playing position, and power output would assist in the development of position-specific training programmes.

A surrogate field-based measure of lower-body power is maximum vertical jump height [15,59,90,91,157,172,210]. A summary of reports of vertical jump performance in professional rugby union players is presented in Table 2.11. Care should be taken when comparing results between studies as there are several methodological factors that may influence jump performance. These factors include the measurement method, differences in protocol, and incorporation or lack of arm swing during the jump. Nevertheless, the vertical jump test provides a practical option for measuring lower-body power in rugby players. The maximum vertical jump height of professional rugby union backs is generally superior to that of forwards [135,172]. These results support the trends observed in previous reviews [78,187].
Table 2.11. Maximum vertical jump height of professional rugby union players; mean ± SD.

<table>
<thead>
<tr>
<th>Source</th>
<th>Level</th>
<th>Jump height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(# of players)</td>
<td>Forwards</td>
</tr>
<tr>
<td>Babault et al, 2007 [15]</td>
<td>Professional provincial</td>
<td>40.1 ± 4.3</td>
</tr>
<tr>
<td>(n = 25)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crewther et al, 2012 [59]</td>
<td>Professional provincial</td>
<td>39.6 ± 8.6</td>
</tr>
<tr>
<td>(n = 48)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elloumi et al, 2008 [91]</td>
<td>International</td>
<td>35.5 ± 4.0</td>
</tr>
<tr>
<td>(n = 20)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elloumi et al, 2009 [90]</td>
<td>International</td>
<td>35.1 ± 4.1</td>
</tr>
<tr>
<td>Forwards (n = 12)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backs (n = 10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kilduff et al, 2008 [157]</td>
<td>Professional provincial</td>
<td>36.0 ± 1.2</td>
</tr>
<tr>
<td>(n = 20)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maso et al, 2002 [172]</td>
<td>International</td>
<td>39.0 ± 5.6</td>
</tr>
<tr>
<td>Forwards (n = 10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backs (n = 10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Randell et al, 2011 [210]</td>
<td>Professional provincial</td>
<td>64.0 ± 7.0</td>
</tr>
<tr>
<td>(n = 13)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Multiple values for one study represent where players were split into several groups.

Only limited published information exists on the strength characteristics of rugby sevens players. A study of 12 club-level players demonstrated increases in gym-based strength assessments following a six-week resistance-training programme conducted while players were concurrently performing two additional sport-specific training sessions per week [58]. Improvements in bench press (11% improvement to 123 ± 21 kg, mean ± SD), back squat (13% improvement to 162 ± 22 kg), deadlift (13% improvement to 176 ± 23 kg), military press (10% improvement to 78 ± 10 kg), and chin-up (6% improvement to 116 ± 15 kg) 1-RM strength were observed after training. The applicability of these findings to players competing at higher levels of competition is unclear, as international-level players may follow quite different training schedules and there are currently no published data on the strength and power characteristics of top-level rugby sevens players. Details on the strength and power characteristics of these players would provide valuable information to guide physical development programmes and inform the transition of players between the two rugby formats.
Speed

Speed is an essential physical fitness component for high-level rugby players [234]. Sprinting speed is typically separated into two related phases: acceleration and maximal velocity. Accelerations in rugby union and rugby sevens are often associated with principal facets of the match, such as the ability to move into a position to receive the ball or move toward or away from an opponent to make or evade a tackle. A player’s maximal velocity is an important factor during sprints over extended distances. Professional rugby union backs are faster than forwards over sprint distances ranging from 10 to 200 m [62,135,234,250]. Sprint times of professional rugby union players between 5 and 40 m reported in research are summarised in Figure 2.6. The sprint times over 10, 20, and 30 m of the Tunisian national rugby sevens team were reported to be 1.80 ± 0.07, 3.09 ± 0.07, and 4.28 ± 0.12 s, respectively [88]. In other field-based testing, Super 12 rugby union backs (9.4 ± 0.4 m·s\(^{-1}\)) achieved a significantly higher (0.9 ± 0.4 m·s\(^{-1}\)) maximal velocity than forwards (8.5 ± 0.4 m·s\(^{-1}\)) during a 60-m sprint [83].

![Figure 2.6. Compilation of sprint times of professional rugby union players reported between 2003 and 2012 [15,30,62,63,78,111,122,210,234,271].](image)

Substantial differences in the speed characteristics of players in individual rugby union positions have been reported [135]. These differences are reflected in the requirements of each position during competition. The outside backs are the fastest players over 40 m, whereas props are the slowest [135]. During rugby union matches there are also differences between backs and forwards in the frequency of starting velocities of sprints. Analysis of
Super 12 matches showed forwards commence most sprints from a standing start (41%) [83]. In contrast, for backs the frequency of starting speeds varied between standing (29%), walking (29%), jogging (29%), and occasionally striding (13%) [83]. The discrimination in acceleration and maximal velocity requirements between backs and forwards during competition highlights the need for position-specific speed training programmes [83]. Such speed development programmes should also incorporate ball-carrying technique, which can affect a player’s sprint speed [116,268]. Differences in speed requirements specific to backs and forwards in rugby sevens competition are unclear.

**Seasonal Variations in Physical Characteristics and Capacities**

Professional rugby union players compete in several competitions in a calendar year. Consequently, it is not uncommon for elite players to compete in 30 to 40 matches in a 12-month period. Many of these matches also require substantial travel which can have profound implications on players’ health and performance [214,226]. It is the objective of any physical preparation programme to maximise the opportunity for players to perform in competition while minimising the risk of injury and illness. Accordingly, the cyclic annual training plan for professional rugby players is typically structured into distinct phases each with its own goals. The pre-season period is crucial in developing the physical and physiological attributes required for successful competition performance. This phase is characterised by a high training volume with increasing intensity. During the competition season, the objective of the training programme is maintenance of the improvements in lean body mass, strength and power, speed, and endurance achieved during pre-season training. This outcome is challenging as training volume is often reduced and additional training goals are introduced or emphasised, such as technical and tactical development. The off-season period provides players with an interval for physical and psychological recovery and recuperation. The post-season phase usually includes a reduction or even cessation of training.

The physical status of players will fluctuate over a season based on the nutritional strategies employed and the priorities for conditioning and resistance training. There is limited research on the changes in physical and physiological characteristics of rugby union players during a competition season, and currently no longitudinal information on rugby sevens players. Four weeks of intensive pre-season training with 33 Super Rugby players yielded moderate increases in bench press strength, box squat strength, and mid-thigh girth and small increases in fat-free mass and flexed upper-arm arm girth [4]. These changes accompanied a moderate increase in perceptions of fatigue, thought to partially explain small decrements in power-
oriented measurements. Conversely, 34 English Division One (second tier) professional rugby union players showed a deterioration in strength and power, and anaerobic and aerobic performance tests (-10.5 ± 38.5 to -1.5 ± 9.3%, mean change ± SD), coupled with a 5.5 ± 38.5% increase in sum of seven skinfolds thickness and -0.6 ± 9.3% decrease in body mass, as a result of a six-week cessation of structured training in the post-season period [191].

Professional rugby union players can improve bench press strength and chin-up strength during the competitive season by 1.8 and 1.9% of pre-season values, respectively [16]. Similarly, a study of Super Rugby players measuring upper- and lower-body strength and power parameters on up to five occasions during a 13-week competitive season reported a small increase in box squat strength and maintenance of bench press strength [8]. Decreases observed in lower- and upper-body power measures were small and trivial, respectively. To identify potential mechanisms for the variations observed within a season, testosterone and cortisol steroid hormones were also measured as markers of the biological anabolic and catabolic environment. Testosterone and cortisol increased moderately over the competitive season, whereas there was a small decline in the testosterone-to-cortisol ratio. Relationships between hormonal concentrations and strength and power measures were unclear.

Changes in anthropometric measures within and between seasons appear to be dependent upon a player’s positional group. An examination of Super Rugby players from one team between 1999 and 2003 found trivial changes in mean results for sum of seven skinfolds thickness within and between seasons in backs [82]. Simultaneously, forwards showed a small decrease in the sum of skinfolds from pre-season (November to January) to the Super 12 competition (February to May). Following the Super 12 season, the forwards had a small increase in skinfolds during the club season (June to September). Changes in body mass and lean mass index for both forwards and backs during the competitive season were trivial. Improvements or decrements in a player’s anthropometry and components of fitness are specific to the phase of the season. Jointly, these findings highlight the utility of monitoring a player’s physical and physiological status over the course of a season to identify changes and modify the physical preparation programme accordingly.

**Relationships between Player Characteristics and Performance**

Although the characteristics of rugby union players have been well documented and information on rugby sevens players is emerging, little is known about the relationships between player characteristics and playing performance. The priorities and specificity of
physical training stimuli should reflect the degree to which each facet of fitness contributes to match performance. For example, the significance of a player’s speed and acceleration development is diminished if this characteristic does not transfer to an improvement in playing performance. Indeed, a conceptual model has been presented in which fitness tests, representative of specific physical characteristics, can be measured to signify the physical constructs of team performance through a causal indicator, such as the quantity of high-intensity activity performed during a match [147].

A study of 510 national provincial-, professional-, and international-level rugby union players identified relationships between fitness testing results and performance indicators during 296 matches [234]. Small to moderate negative correlations were present between sprint times and line breaks, metres advanced, tackle breaks, and tries scored. Percentage of body fat and mean repeated-sprint time in the forwards, and decrement in repeated-sprint ability in the backs, had small to moderate associations with activity rate on and around the ball. As may be expected, the small to moderate relationships between physical testing scores and key performance indicators demonstrate factors other than physical characteristics account for a large portion of match statistics. However, associations between the aforementioned performance indicators and successful phase and team outcomes infer the relative importance of physical characteristics to on-field events [153,195,223,272].

The potential compromise between muscularity and endurance is demonstrated by the nature of relationships between players’ anthropometric characteristics and measures of locomotive work-rate. Mesomorphy and muscle mass were negatively correlated with the amount of high-intensity running performed by players during matches of an international rugby sevens tournament in 1996 [216]. During this tournament though, neither anthropometric profiles nor work-rate measures were able to distinguish between winning and losing teams. These findings are in contrast to a similar study of the anthropometric characteristics of rugby sevens players which reported significant differences in estimates of absolute and relative muscle mass, absolute bone mass, relative body fat, endomorphy, and mesomorphy between players of teams that finished in the top and bottom four rankings during two tournaments in 1996 and 1997 [215]. Greater muscle mass is advantageous during contact situations and contests for possession such as scrums, rucks, and mauls. Although the associations between muscle mass and high-intensity running do not imply a causal relationship, they indicate the potential for increased muscle mass to be associated with a faster onset of fatigue. Further investigation is required to verify this relationship in rugby union and rugby sevens players.
Physical Development and Training Interventions

Although frameworks for the medium- to long-term physical development of elite-level rugby union players have been proposed [81,109], most contemporary studies of physical development programmes and training interventions have focused on short-term changes in specific factors relating to competition performance in isolation. More recent research has considered such issues as the effects of hypoxic exposure [119,137], interventions to improve speed and acceleration [49,126,238,271], and gym-based programmes aimed at augmenting measures of strength and power [6,9,56,61,123]. Studies have also examined other methods to improve markers of performance, including electromyostimulation to improve muscle strength and power [15] and skill-based conditioning games to improve cardiorespiratory fitness [110]. In contrast, studies of training programmes to improve rugby-specific skills have received little attention [138], and only in rugby union players.

Mixed-method training programmes (incorporating both resistance and on-field training) over multiple weeks are beneficial in developing a variety of physical qualities in adolescent [235] and professional [4] rugby union players and international rugby sevens players [58,88]. Although many novel training strategies can improve physical qualities and indicators relevant to rugby performance, most research has focused on sub-elitie players. Differences in the player characteristics, competition demands, and training habits between sub-elitie or junior players and top-level professional players may limit the application of these findings. As an example, only one study of adolescent players has examined the specificity of on-field training activities in comparison to matches [128]. Examination of the specificity of typical training practices of international rugby sevens players would support the development of physical preparation programmes that replicate the demands of competition and optimise the efficiency of training time.

Conclusions

There is a growing body of knowledge on the tactical, physical, and physiological demands of rugby union competition and the anthropometric, physical, and physiological characteristics of players of various positions to meet these demands. Generally, rugby union forwards are heavier and taller compared with backs, and have higher absolute results for strength, aerobic capacity, and anaerobic power. These characteristics assist forwards in the higher contact demands during matches than backs, and associated increased cardiovascular load. In contrast, rugby union backs are typically leaner and faster compared with forwards,
and have greater muscular power production and aerobic capacity when values are expressed relative to body mass. Such qualities support the greater distances covered by backs during matches and higher sprint demands compared with forwards. Although, the observed evolution of rugby union dictates that ongoing research is required to meet the changing characteristics of players and match activities at different levels of competition.

Comprehensive investigations of the characteristics of players, fitness requirements, and movement patterns during competition available in rugby union do not currently exist in rugby sevens. This information is required to guide development of effective evidence-based physical preparation programmes. Given the increased worldwide popularity of rugby sevens and the corresponding interest in the contribution of sports science to training and competition performance, three main priority areas emerge for future applied research in the sport. Firstly, research is required to establish the technical, tactical, and physical demands of the sport. Investigations in this area will determine the key differences between rugby union and rugby sevens and quantify the effects of changes to the game format, such as the reduced number of players on the field and the tournament style of competition. Secondly, analysis of the characteristics of players currently competing at the international level will help establish the requirements for competition. Comparing and contrasting the qualities of rugby sevens and professional rugby union players will also assist development of talent identification and transfer programmes. Finally, once the requirements of rugby sevens competition and priorities for physical and physiological development are established, future research should investigate methods of training which maximise adaptations to benefit performance while minimising the risk of injury. Findings from research into these three key areas will inform strategies designed to improve specific components of rugby sevens performance.
Chapter Three - Performance Indicators Related to Points Scoring and Winning in International Rugby Sevens


**Abstract**

Identification on performance indicators related to scoring points and winning is needed to inform tactical approaches to international rugby sevens competition. The aim of this study was to characterise team performance indicators in international rugby sevens and quantify their relationship with a team’s points scored and probability of winning. Performance indicators of each team during 196 matches of the 2011/2012 International Rugby Board Sevens World Series were modelled for their linear relationships with points scored and likelihood of winning within (changes in team values from match to match) and between (differences between team values averaged over all matches) teams. Relationships were evaluated as the change and difference in points and probability of winning associated with a two within- and between-team standard deviations increase in performance indicator values. Inferences about relationships were assessed using a smallest meaningful difference of one point and a 10% probability of a team changing the outcome of a close match. All indicators exhibited high within-team match-to-match variability (intraclass correlation coefficients ranged from 0.00 to 0.23). Excluding indicators representing points-scoring actions or events occurring on average less than once per match, 13 of 17 indicators had substantial clear within-team relationships with points scored and/or likelihood of victory. Relationships between teams were generally similar in magnitude but unclear. Tactics that increase points scoring and likelihood of winning should be based on greater ball possession, fewer rucks, mauls, turnovers, penalties and free kicks, and limited passing.

**Key words:** match analysis, modelling, notational analysis, performance analysis, rugby union, statistics
Introduction

Rugby sevens is a complex team sport requiring a combination of fitness and physical ability [132,133], execution of technical skills [175], and tactical and strategic considerations [144] for success at the international level. The dynamic match environment can make it difficult for coaches and support staff to identify which elements of physical, technical, and tactical development to target to enhance the probability of successful performance. Match analysis is often used to provide an objective and unbiased record of team activity to assess and monitor performance. However, it is unclear which performance indicators should be monitored to evaluate team performance in rugby sevens.

A performance indicator is a variable that characterises some aspect of performance [146]. To be meaningful and useful, performance indicators should be related to a successful performance outcome. Research is required to characterise the technical and tactical aspects of team play related to successful performance in rugby sevens. In team sports such as rugby sevens, the primary criterion for assessing a team’s performance is the match outcome, determined by the points scored by each team. The final point difference, that is, the margin of victory or loss, provides important contextual information relating to how well matched the competing teams are and the relative success of the tactics and strategies employed. Team performance indicators should therefore be considered in relation not only to winning [153,195], but also points scored in close matches [263,264].

Team performance indicators describing individual or collective skills or match events may fluctuate as a function of environmental conditions, officiating style, and each team’s technical strengths and weaknesses. Analyses of limited data sets, such as those of a single tournament or team, may be heavily influenced by these variables and not truly representative of international-level competition. By analysing a large sample of matches from different national teams, played under varying conditions, issues related to match volatility are minimised and performance indicators commonly associated with successful performances can be identified.

Identifying performance indicators related to scoring points and winning in rugby sevens may be used to develop reference values for international matches. These values can be used by coaches and support staff to inform practical guidelines for technical and tactical development. Knowledge of performance indicators can also be used to create performance profiles to predict team behaviours and performance outcomes. The purpose of this study was
to characterise common team performance indicators in international rugby sevens matches and calculate the typical within-team variability and between-team differences in these values. The effect of changes or differences in performance indicators on points scoring and probability of winning within and between teams was then quantified.

**Methods**

**Sample**

Match statistics from 196 men’s international matches played over four tournaments of the 2011/2012 International Rugby Board (IRB) Sevens World Series were analysed. Match data were retrieved from the official IRB tournament website (http://www.irbsevens.com). Team performance indicators representing totals of a given event for each team in each match were divided into four categories: match development, scoring, set-piece play, and phase play (Table 3.1). Match development indicators described the time with the ball and number of law infringements for a given team. Scoring indicators described the number of points scored or conceded and the way and frequency in which points were scored. Set-piece play indicators described the frequency and outcome of line-outs thrown, scrums fed and restarts kicked by the team. Phase play indicators described how the team used the ball when in possession. The performance indicators were analysed as absolute values and as values standardised per min of possession time or per try scored.

<table>
<thead>
<tr>
<th>Category</th>
<th>Team performance indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Match development</td>
<td>Possession time, penalties and free kicks conceded, yellow cards</td>
</tr>
<tr>
<td>Scoring</td>
<td>Points scored, points conceded, tries scored, tries conceded, tries scored per min of possession, conversions</td>
</tr>
<tr>
<td>Set-piece play</td>
<td>Line-outs, line-out possessions retained, scrums, scrum possessions retained, restarts, restarts regained</td>
</tr>
<tr>
<td>Phase play</td>
<td>Passes, passes per min of possession, passes per try scored, rucks, rucks per try scored, rucks retained, mauls, rucks and mauls per min of possession, ruck and maul retention, kicks, kicks per min of possession, turnovers conceded, turnovers conceded per min of possession</td>
</tr>
</tbody>
</table>
Statistical Analysis

Data were imported into the Statistical Analysis System (version 9.3, SAS Institute, Cary, NC) for analysis. Mean values and true between-team and within-team standard deviation for common team performance indicators were calculated using a mixed-model reliability analysis with a random effect for team. Mean values were estimated as the intercept of the model with the between-team standard deviation calculated from the random effect, and the within-team standard deviation calculated from the residual variance. A standard deviation representing observed between-team match-to-match typical differences was calculated as the square root of the sum of the true between-team and within-team variances. Intraclass correlation coefficients representing match-to-match reliability of performance indicators were calculated as the true between-team variance divided by the observed between-team variance.

Performance indicators representing events occurring on average more than once per match, and not directly representing points-scoring actions, were further analysed for their relationship with points scored by a team and the probability of winning. A mixed model with the performance indicator as a linear fixed effect, a random effect for team, and an interaction effect for performance indicator and team, was employed to characterise the relationship between the performance indicator and points scored within each team. This model allowed for the possibility of individual team differences in the relationship between the performance indicator and points scored. An additional interaction effect for team and the tournament at which matches were played, allowing for individual team differences in the relationship at different tournaments, was removed from the model because it explained no additional variance in points scored. A linear relationship between performance indicators and points scored was deemed appropriate after assessment of a quadratic trend yielded no additional meaningful information. A linear model was also favoured for its simpler interpretation. The effect of a change within a team in performance indicator value on points scored was assessed by multiplying the slope of the relationship by two within-team standard deviations [141]. Two standard deviations represents the change within a team from a typically low performance indicator value (-1 SD) to a typically high value (+1 SD).

A between-team effect of the selected indicators was assessed by averaging the values of the performance indicator and points scored for each of the 26 teams. The effect of the performance indicator was derived by multiplying the slope of the linear relationship between
the means by twice the standard deviation of the teams’ mean values of the performance indicator.

Generalised linear modelling was used to estimate the effect of an increase in performance indicator value on a team’s probability of winning. Cumulative logistic regression was employed to model categorical match outcomes of a win or loss, allowing for the inclusion of drawn matches. The addition of a random effect for team allowed for individual team differences. The logarithm of the odds ratio of winning was calculated and the effect of a two within- and between-team means standard deviation increase in the performance indicator value expressed as a percent change or difference in the likelihood of a team winning a close match (probability of winning centred on 50%).

Possible confounding effects of two important performance indicators (passes per min of possession and rucks and mauls per min of possession) were analysed by assessing the effects of a two standard deviation increase in the performance indicator after adjusting for the second indicator by adding it to the model as a covariate. The results of these analyses did not change the inferences about the effect on points and probability of winning and are therefore not shown.

Inferences about effects of performance indicators were assessed using the smallest meaningful difference in points scored during close matches. In this context, close matches were defined as those with a final points score difference of ≤7, corresponding to match outcomes decided by a converted try or less (41% of observed matches, n = 80). The smallest meaningful difference is given by 0.3 of the typical variation between competitions of an athlete’s or team’s performance [140]. This difference was calculated as the standard deviation of the points difference in close matches (4.5) multiplied by 0.3/√2, equal to approximately one point. The formula was divided by the square root of two to account for the combined random variation in the performance of the two teams contesting a match. The smallest meaningful difference represents the difference in a team’s points score required to change the match outcome in ~10% of close matches. Similarly, 10% was defined as the smallest meaningful difference in the analyses of a team’s probability of changing a match outcome. A 10% difference represents one extra win or loss in 10 evenly-balanced matches. An inference about the true value of an effect was based on the uncertainty of its magnitude. When the 90% confidence interval crossed the threshold for both negative and positive values of the smallest meaningful difference, the effect was deemed unclear [141].
Results

Values for match development, scoring, set-piece play and phase play indicators in a typical match summarised by the mean and observed standard deviation are presented in Table 3.2. The observed standard deviation consists of contributions from the between-team standard deviation, representing the stable typical differences between teams, and the within-team standard deviation, representing the typical variability a team shows between matches. All performance indicators exhibited higher variability in changes within teams than differences between teams. The intraclass reliability correlation coefficients ranged from 0.00 to 0.23.
Table 3.2. Rugby sevens team performance indicator values per team per match (n = 392 observations, 196 international matches).

<table>
<thead>
<tr>
<th>Performance Indicator</th>
<th>Mean; ±90% CL</th>
<th>Observed SD*</th>
<th>Between-team SD†</th>
<th>Within-team SD*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Match Development</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Possession time (s)</td>
<td>213; ±7</td>
<td>52</td>
<td>14</td>
<td>50</td>
</tr>
<tr>
<td>Penalties and free kicks conceded</td>
<td>3.26; ±0.20</td>
<td>1.86</td>
<td>0.33</td>
<td>1.83</td>
</tr>
<tr>
<td>Yellow cards</td>
<td>0.15; ±0.03</td>
<td>0.37</td>
<td>0.00</td>
<td>0.37</td>
</tr>
<tr>
<td><strong>Scoring</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Points scored</td>
<td>15.6; ±1.6</td>
<td>10.5</td>
<td>3.8</td>
<td>9.7</td>
</tr>
<tr>
<td>Tries scored</td>
<td>2.5; ±0.3</td>
<td>1.6</td>
<td>0.6</td>
<td>1.5</td>
</tr>
<tr>
<td>Tries scored per min of possession</td>
<td>0.72; ±0.07</td>
<td>0.46</td>
<td>0.15</td>
<td>0.44</td>
</tr>
<tr>
<td>Conversions</td>
<td>1.5; ±0.2</td>
<td>1.3</td>
<td>0.4</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>Set-piece Play</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line-outs</td>
<td>1.06; ±0.13</td>
<td>1.08</td>
<td>0.23</td>
<td>1.06</td>
</tr>
<tr>
<td>Line-out possessions retained</td>
<td>0.79; ±0.12</td>
<td>0.93</td>
<td>0.25</td>
<td>0.89</td>
</tr>
<tr>
<td>Scrums</td>
<td>1.90; ±0.13</td>
<td>1.27</td>
<td>0.16</td>
<td>1.26</td>
</tr>
<tr>
<td>Scrum possessions retained</td>
<td>1.78; ±0.12</td>
<td>1.26</td>
<td>0.14</td>
<td>1.25</td>
</tr>
<tr>
<td>Restarts</td>
<td>3.06; ±0.19</td>
<td>1.40</td>
<td>0.44</td>
<td>1.33</td>
</tr>
<tr>
<td>Restart regained</td>
<td>0.76; ±0.13</td>
<td>0.94</td>
<td>0.27</td>
<td>0.90</td>
</tr>
<tr>
<td><strong>Phase Play</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passes</td>
<td>33.7; ±1.4</td>
<td>11.7</td>
<td>2.8</td>
<td>11.3</td>
</tr>
<tr>
<td>Passes per min of possession</td>
<td>9.36; ±0.26</td>
<td>1.93</td>
<td>0.56</td>
<td>1.85</td>
</tr>
<tr>
<td>Rucks</td>
<td>8.4; ±0.6</td>
<td>4.1</td>
<td>1.4</td>
<td>3.8</td>
</tr>
<tr>
<td>Rucks per try scored</td>
<td>4.4; ±0.5</td>
<td>3.9</td>
<td>1.1</td>
<td>3.7</td>
</tr>
<tr>
<td>Mauls</td>
<td>0.43; ±0.09</td>
<td>0.74</td>
<td>0.18</td>
<td>0.71</td>
</tr>
<tr>
<td>Rucks and mauls per min of possession</td>
<td>2.46; ±0.16</td>
<td>0.86</td>
<td>0.41</td>
<td>0.76</td>
</tr>
<tr>
<td>Ruck and maul retention (%)</td>
<td>79.3; ±1.7</td>
<td>15.6</td>
<td>2.8</td>
<td>15.4</td>
</tr>
<tr>
<td>Kicks</td>
<td>1.18; ±0.17</td>
<td>1.20</td>
<td>0.39</td>
<td>1.14</td>
</tr>
<tr>
<td>Kicks per min of possession</td>
<td>0.36; ±0.05</td>
<td>0.38</td>
<td>0.12</td>
<td>0.36</td>
</tr>
<tr>
<td>Kicks per pass</td>
<td>0.043; ±0.007</td>
<td>0.053</td>
<td>0.014</td>
<td>0.051</td>
</tr>
<tr>
<td>Rucks and mauls per kick</td>
<td>6.3; ±0.6</td>
<td>4.2</td>
<td>1.2</td>
<td>4.0</td>
</tr>
<tr>
<td>Turnovers conceded</td>
<td>2.42; ±0.15</td>
<td>1.51</td>
<td>0.20</td>
<td>1.49</td>
</tr>
<tr>
<td>Turnovers conceded per min of possession</td>
<td>0.72; ±0.05</td>
<td>0.48</td>
<td>0.09</td>
<td>0.47</td>
</tr>
</tbody>
</table>

CL = confidence limits; 90% confidence limits: *×/÷1.1, †×/÷1.4 to 5.8.

Of the 17 performance indicators analysed, 13 had a clear substantial relationship with points scored within teams (Figure 3.1A). The only unclear within-team relationships with points scored were for line-out possessions retained and kicks per min of possession. Of the
indicators demonstrating clear relationships, scrums and scrum possessions retained had trivial effects (within the positive and negative thresholds for the smallest meaningful difference). In contrast, the only clear between-team relationships with points scored were for rucks and mauls per min of possession, penalties and free kicks conceded, passes per min of possession, scrum possessions retained, possession time, and percentage of ruck and maul retention (Figure 3.1A). Rucks and mauls per min of possession had the strongest relationship with points scored. Figure 3.2 shows the differences in mean rucks and mauls per min of possession between teams and substantial negative between- and within-team relationships with points scored in a match.
Figure 3.1. Effect of two standard deviations of within-team changes and between-team differences of team performance indicators on (A) points scored during an international rugby sevens match, and (B) likelihood of winning a close match. Bars are 90% confidence intervals. Dotted lines represent thresholds for smallest meaningful difference: (A) ±1 point and (B) ±10%. Where error bars simultaneously cross the negative and positive values of the smallest meaningful difference, the effect is unclear.
Chapter 3 – Performance Indicators Related to Points Scoring and Winning in International Rugby Sevens

Figure 3.2. Example of strong between- and within-team relationships between a performance indicator (rucks and mauls per min of possession) and points scored in international rugby sevens matches. Each filled triangle represents the mean values for one of 26 teams. Best-fitting lines are shown with symbols representing increments of one between- and within-team standard deviation (open circles and filled squares, respectively). Dotted and dashed lines represent the 90% confidence limits of predicted mean points scored for the between- and within-team relationships, respectively.

Results for analyses of the effect of performance indicators on the likelihood of winning close matches generally followed the trends for points scoring (Figure 3.1B). All within-team effects of performance indicators on probability of winning were clear. However, rucks and mauls retained, penalties and free kicks conceded, number of line-outs, line-out possessions retained, kicks per min of possession, and passes had a trivial effect. For the between-team analyses, a team with two standard deviations higher number of rucks and mauls per min of possession, turnovers conceded per min of possession, passes, and passes per min of possession on average had a 15 to 28% lower probability of winning a close match. Conversely, two standard deviations greater ruck and maul retention, possession time, number of scrums, number of line-outs, and scrum possessions retained resulted in an 11 to 31% higher likelihood of winning an even match. All other between-team effects on the probability of winning were unclear or trivial.

Discussion
This is the first study of the relationship of performance indicators and points scoring or probability of winning in rugby sevens. Analysis of match statistics collected from a large
sample of matches during four international tournaments allowed reference values for common team performance indicators to be generated. The analysis also quantified the typical variability between matches in performance indicator values for a given team. There was greater variability in changes in performance indicator values within a team than between teams. Excluding performance indicators representing points-scoring actions or events occurring on average less than once per match, 13 of 17 indicators had substantial clear relationships with a team’s points score and/or likelihood of victory. In general, the within- and between-team effects of performance indicators were similar for a team’s points score and probability of winning an evenly-contested match. An increase or positive difference in rucks and mauls per min of possession had the largest negative association with a team’s points and likelihood of winning. Conversely, the percentage of rucks and mauls retained had the largest positive effect. The observed relationships indicate priorities for technical and tactical development of teams at the international level.

The relationships between performance indicators, points scoring and likelihood of winning support findings from international matches played in 2001, which identified differences in the tactics employed by successful and unsuccessful teams [144]. When in possession of the ball, successful teams adopted a more evasive style of play, whereas unsuccessful teams were more direct in their patterns of play. The current findings of higher possession time having a positive effect on points scoring and chances of winning are in agreement with these observations, suggesting successful teams are more patient and have greater control of the game. A more direct approach, resulting in a higher frequency of rucks and mauls, was related to a lower points score and probability of a successful match outcome, even when the ruck and maul possession was retained. Unsurprisingly, a higher point score was associated with greater relative ruck and maul possession retention, and fewer turnovers in possession and penalties and free kicks conceded.

Absolute frequency of passing and kicking within a team were positively related with points scored, but when these actions were standardised relative to possession time the results were reversed and unclear, respectively. The positive relationships of absolute frequency of these events and points scoring appear more indicative of the higher ball possession time of higher-scoring teams than the technical actions alone. During international matches played in 2001, successful teams tended to kick less frequently than less successful teams [144]. Furthermore, although the number of passes per match was similar between the teams, successful teams performed fewer normal passes and loop passes, and more miss (cut-out) passes and dummy
passes [144]. These differences, coupled with the fewer rucks and mauls performed by successful teams, suggest the tactical approach of better teams is to keep the ball “alive” and attack with more width and deception in preference to going into contact when in possession.

To increase the opportunities for points-scoring movements and probability of winning in international competition, teams should aim to maintain ball possession. The importance of maintaining possession concurs with the observation that teams progressing beyond the quarter-final in the 2005 IRB Rugby World Cup Sevens secured and maintained control of the ball for periods between 30 and 60 s, and converted over 30% of possessions into points-scoring movements [261]. The possession-based approach of successful teams in international rugby sevens contrasts with observations in international rugby union competition. Winning in international rugby union has been associated with a territory-based strategy, where teams are more likely to kick the ball when in possession [33,195]. The difference in successful tactics between rugby sevens and rugby union likely represents the additional space available for players in the abridged format. The reduced number of players on the field in rugby sevens increases the opportunity for teams to initiate points-scoring movements from any position on the field. This scenario results in a greater importance of ball possession and less significance of field position and set-piece plays.

Teams conceding more penalties and free kicks tended to score fewer points. Nevertheless, the effect on the likelihood of winning was unclear between teams and trivial within teams. In 2001, successful international teams with a win rate of ≥70% conceded more penalties per match than unsuccessful teams [144]. This discrepancy in the number of penalties conceded may be explained by successful teams being more likely to utilise the advantage rule to continue play following an infringement by the opposition. Although conceding points to the opposition through penalty goals is very rare in rugby sevens (and hence not included in Table 3.2), conceding penalties and free kicks limits a team’s opportunities to score by giving the opposition territory and possession. The association between poorer discipline and lower scoring performances warrants further investigation into the timing and circumstances of penalties and free kicks being awarded. It is unclear whether there are differences between successful and unsuccessful teams in the frequency of law infringements when in possession of the ball or when defending.

Previous studies of team performance indicators have been limited by analytical methods that consider only the collective characteristics of successful and unsuccessful performances,
leading to subtleties in individual team performances becoming indistinguishable [246]. The limitation of generalising trends in match statistics to individual teams was accounted for in the current study by analysing the relationship of within-team changes in performance indicators with points scoring and probability of success. This model allowed individual differences between teams in tactical approaches to be preserved while still estimating the mean effect on points scored and likelihood of winning. The within-team relationships characterised in this study represent the observed and achievable change in points scored and odds of winning as a team changes its performance indicator, whereas the between-team relationships represent stable long-term differences in performance between teams. A similar approach could be employed to determine the influence of performance indicators on success in other sports and with other frequent match events or player actions.

It should be noted that the analysis of the relationships between performance indicators, points scoring and winning does not imply a cumulative effect when indicators are combined. Although it is possible to prioritise the importance of individual statistics based on their association with scoring and successful outcomes, it is likely there are substantial correlations between some performance indicators. For example, in most matches, increasing a team’s absolute possession time will simultaneously restrict their opposing team’s possession. However, preliminary analyses of the effects of a performance indicator adjusted for a second performance indicator demonstrated independent effects on points scoring and probability of winning (results not shown). These results suggest that in some circumstances a team’s performance may be improved by independently changing performance indicator values.

Given the open nature of rugby sevens with additional space afforded to players compared with 15-player rugby union, defensive actions and structures are crucial in determining the outcome of matches. The current study focused on performance indicators representative of actions performed by teams when in possession of the ball. As it is impossible to maintain possession of the ball for an entire match, future studies could investigate relationships between defensive performance indicators and points scored by the opposition. This investigation was limited to official match statistics routinely collected by the IRB during the international IRB Sevens World Series. Subsequent research should examine additional performance indicators that may further inform the technical and tactical preparation of teams for competition.
While it is apparent the team performance indicators described in this study are representative of technical and tactical factors associated with successful match outcomes, clearly other elements also influence team performance. Factors such as players’ physiques, fitness and physical ability, skill and technical proficiency are all determinants of the success of a team. Although some of the performance indicators examined may be partially representative of these factors and the strategies employed by successful teams, coaches must consider the interaction of the multitude of components related to performance in rugby sevens at the international level.

**Conclusion**

Coaches and support staff can use the performance indicator values presented in this study as a reference to monitor and assess the performance of their team as well as opposing teams. Coaches can then devise strategies and assign priorities for team preparation based on each performance indicator’s effect on points scoring and chances of winning. There is greater variability in within-team changes than between-team differences in team performance indicator values. The associations of performance indicators with points scoring and probability of winning suggest higher-scoring and more-successful teams tend to control possession of the ball and play a patient, disciplined and evasive style of game. A less disciplined and more direct approach, characterised by conceding more penalties and free kicks and performing more rucks and mauls, gives the opposition greater opportunity to gain ball possession and is associated with lower scores. Team tactics that maximise the amount of points scored and likelihood of winning should be based on strategies that promote greater ball possession, minimise rucks and mauls, turnovers, penalties and free kicks, and limit passes.

**Key Points**

- Successful international rugby sevens teams tend to maintain ball possession; more frequently avoid taking the ball into contact; concede fewer turnovers, penalties and free kicks; retain possession in scrums, rucks and mauls; and limit passing the ball.
- Selected performance indicators may be used to evaluate team performances and plan more effective tactical approaches to competition.
- There is greater match-to-match variability in performance indicator values within than between international rugby sevens teams.
The priorities for a rugby sevens team’s technical and tactical preparation should reflect the magnitudes of the relationships between performance indicators, points scoring and the likelihood of winning.
Chapter Four - Relationships between Rugby Sevens Performance Indicators and International Tournament Outcomes


**Abstract**

**Objectives:** Identifying performance indicators related to rugby sevens competition outcomes will inform development of team tactics that increase the likelihood of success. This study characterised 16 team performance indicators and quantified the effect of changes and differences in performance indicators within and between teams on team ranking in international tournaments.

**Design:** Official tournament statistics and final ranking of each team in each of nine men’s tournaments of the 2011/2012 International Rugby Board Sevens World Series were analysed in a retrospective longitudinal design.

**Methods:** Novel analyses involving linear mixed modelling quantified the effects within and between teams of an increase in performance indicators from a typically low to typically high value on the logarithm of the tournament ranking. Magnitudes of effects were assessed using a smallest meaningful difference in ranking.

**Results:** Three performance indicators had substantial within-team effects and twelve had substantial between-team effects on tournament ranking. More entries into the opposition’s 22-m zone per match, tries per entry into the opposition’s 22-m zone, tackles per match, passes per match, rucks per match and a higher percentage of tackle completion were associated with a better mean ranking. Conversely, more passes per try, rucks per try, kicks per try, errors per match, surrendered possessions per match, and missed tackles per match were related to a worse ranking.
Chapter 4 – Relationships between Rugby Sevens Performance Indicators and International Tournament Outcomes

*Conclusions:* The most successful teams maintain ball possession by reducing errors and turnovers, are efficient in converting possession into tries, and have effective defensive structures resulting in a high rate of tackle completion.

**Key words:** rugby union, statistics, performance analysis, notational analysis, match analysis, modelling
Chapter 4 – Relationships between Rugby Sevens Performance Indicators and International Tournament Outcomes

Introduction

Coaches and support staff incessantly seek to better understand factors that contribute to success in international competition. In rugby sevens, as with other sports, match statistics collected during competition provide useful, objective and critical information on the technical proficiency of teams, strategies, tactics and patterns of play employed by different teams, and key performance indicators that discriminate between successful and unsuccessful teams. The utility of such information provides a valuable description of the nature of the sport and highlights areas for team development and match preparation.

Performance analysis in 15-player rugby union has identified statistics that discriminate between winning and losing teams [195,263,264], examined specific components of play such as rucks [259] and tackles [257,258], quantified changes in match activities over time [205,276], and been used to monitor the performance of individual players [37,164]. However, unlike rugby union, rugby sevens has received little scientific examination despite an increase in worldwide popularity. Rugby sevens differs from rugby union in a number of fundamental ways, including the reduced number of players on the field for each team (seven vs. 15) and shorter match duration (14 vs. 80 min; a 20 min match is played for a tournament final). International competition also differs between the rugby formats, as rugby sevens is played in 2- or 3-day tournaments. The International Rugby Board (IRB) Sevens World Series is an annual series of international rugby sevens tournaments contested by national teams from around the world. In 2016, rugby sevens will debut at the Olympic Games in Rio de Janeiro, Brazil.

While performance analysis studies have been conducted in rugby union, differences in movement patterns [132] and player characteristics [133] as well as the more “open” nature of rugby sevens are likely to impose different technical requirements for success. The purpose of this study was to establish reference values for team performance indicators during international rugby sevens tournaments and identify the most important performance indicators for success by quantifying relationships between match statistics and final team rankings in IRB Sevens World Series tournaments.
Chapter 4 – Relationships between Rugby Sevens Performance Indicators and International Tournament Outcomes

Methods

Sample
A retrospective longitudinal study design was employed. Summary match statistics and final ranking position of teams from nine international men’s tournaments of the 2011/2012 IRB Sevens World Series (392 matches, five or six matches per team per tournament) were retrieved from the official tournament website (http://www.irbsevens.com). The statistics collected for analysis included: passes per match, kicks per match, completed tackles per match, missed tackles per match, percentage of tackle completion, errors per match, surrendered possessions per match, rucks per match, tries per match, rucks per try, kicks per try, passes per try, percentage of restarts regained, percentage of restart errors, entries into opposition’s 22-m zone per match, and tries per entry into opposition’s 22-m zone.

Statistics representing totals over the entire tournament for each match event for each team were expressed as a relative value (e.g., a percentage or per match) to account for differences in the number of matches contested, tries scored and restart kicks taken by each team in each tournament.

Statistical Analysis
Data were imported into the Statistical Analysis System (version 9.3, SAS Institute, Cary, NC) for analysis. The mean value, within-team standard deviation (SD), and true between-team standard deviation for team performance indicators were calculated using mixed model reliability analysis with a random effect for team. The mean value was estimated as the intercept of the model, the between-team standard deviation was calculated from the random effect, and the within-team standard deviation was calculated from the residual variance. A standard deviation representing typical observed tournament-to-tournament differences between teams was calculated as the square root of the sum of the true between-team and within-team variances. Intraclass correlation coefficients representing tournament-to-tournament reliability of performance indicators were calculated as the true between-team variance divided by the observed between-team variance. Final tournament rankings were logarithmically transformed to estimate and give equal importance to percent or factor differences in rankings rather than absolute differences. For example, the difference between second and first is equivalent to the difference between tenth and ninth without transformation (one rank improvement) and between tenth and fifth with transformation (50% improvement).
A linear mixed model with the performance indicator as a fixed effect, a random effect for team, and an interaction effect for performance indicator and team was employed to characterise the relationship between the performance indicator and tournament ranking within each team. The model allowed for the possibility of individual team differences in the relationship between performance indicator and ranking. A linear relationship between performance indicators and ranking was quantified after assessment of a quadratic trend yielded no additional meaningful information. A linear model was also favoured for its simpler interpretation. The effect of a change within a team in performance indicator value on tournament ranking was assessed by multiplying the slope of the relationship by two within-team standard deviations [141], which represented the typical tournament-to-tournament variability in the performance indicator. To delimit the investigation to technical performance indicators instead of point-scoring actions, the relationship between the number of tries scored and tournament ranking was not analysed.

The between-team relationship of the performance indicators with tournament ranking was assessed by averaging the values of the performance indicator and ranking for each team over the nine tournaments. The typical effect of a difference in performance indicator value on ranking was calculated by multiplying the slope of the linear relationship between the means by twice the standard deviation of the teams’ mean performance indicator values [141]. A two standard deviation increase represents the difference between teams with a typically low (-1 SD) and typically high (+1 SD) performance indicator value.

Inferences about effects of within-team changes and between-team differences in performance indicators were assessed using the smallest meaningful difference in tournament ranking. The smallest meaningful improvement was defined as a 20% better ranking (a factor difference of 0.8 of the original ranking). This improvement represents the difference required to move a team’s tournament ranking from fifth to fourth. In IRB Sevens World Series tournaments, a ranking of fifth equates to a team winning the second-tier Plate competition; moving to fourth ensures a team finishes in the top-tier Cup competition, thereby scoring more World Series points. The smallest meaningful decrement in ranking was therefore a move from fourth to fifth, or 25% (a factor difference of 1/0.8 or 1.25).

An inference about the true value of an effect was based on the uncertainty of its magnitude. When the 90% confidence interval concurrently crossed the thresholds for the smallest meaningful decrement and improvement, the effect was deemed unclear [141].
Chapter 4 – Relationships between Rugby Sevens Performance Indicators and International Tournament Outcomes

Results

Tournament reference values for team performance indicators are summarised in Table 4.1. The standard deviation of performance indicator values within teams, representing the typical variability for a team between tournaments, was greater than the between-team standard deviation, representing the typical differences between teams, for the majority of indicators. The between-team standard deviation was larger than the within-team standard deviation for tries per match, rucks per try, kicks per try, passes per try, and entries into opposition’s 22-m zone per match. Intraclass correlation coefficients, corresponding to the proportion of variance in performance indicators accounted for by true between-team differences, ranged from 0.00 to 0.83.

Table 4.1. Reference values for international rugby sevens tournament performance indicators (n = 784 observations during 392 matches, nine tournaments).

<table>
<thead>
<tr>
<th>Performance indicator(^{\dagger})</th>
<th>Mean; ±90% CL</th>
<th>Observed SD*</th>
<th>Between-team SD†</th>
<th>Within-team SD‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passes</td>
<td>31.5; ±1.1</td>
<td>5.6</td>
<td>2.3</td>
<td>5.1</td>
</tr>
<tr>
<td>Kicks</td>
<td>1.23; ±0.16</td>
<td>0.73</td>
<td>0.40</td>
<td>0.61</td>
</tr>
<tr>
<td>Completed tackles</td>
<td>14.9; ±0.7</td>
<td>2.9</td>
<td>1.7</td>
<td>2.4</td>
</tr>
<tr>
<td>Missed tackles</td>
<td>4.3; ±0.3</td>
<td>1.3</td>
<td>0.6</td>
<td>1.2</td>
</tr>
<tr>
<td>Tackle completion (%)</td>
<td>76.9; ±1.6</td>
<td>6.5</td>
<td>4.2</td>
<td>5.0</td>
</tr>
<tr>
<td>Errors</td>
<td>3.41; ±0.18</td>
<td>0.85</td>
<td>0.40</td>
<td>0.75</td>
</tr>
<tr>
<td>Surrendered possessions</td>
<td>8.69; ±0.29</td>
<td>1.39</td>
<td>0.64</td>
<td>1.24</td>
</tr>
<tr>
<td>Rucks</td>
<td>7.72; ±0.61</td>
<td>2.56</td>
<td>1.58</td>
<td>2.01</td>
</tr>
<tr>
<td>Tries</td>
<td>2.35; ±0.27</td>
<td>1.03</td>
<td>0.77</td>
<td>0.68</td>
</tr>
<tr>
<td>Rucks per try</td>
<td>3.90; ±0.62</td>
<td>2.14</td>
<td>1.80</td>
<td>1.17</td>
</tr>
<tr>
<td>Kicks per try</td>
<td>0.77; ±0.20</td>
<td>0.67</td>
<td>0.60</td>
<td>0.29</td>
</tr>
<tr>
<td>Passes per try</td>
<td>16.8; ±2.8</td>
<td>9.2</td>
<td>8.4</td>
<td>3.9</td>
</tr>
<tr>
<td>Restarts regained (%)</td>
<td>22.1; ±2.6</td>
<td>12.7</td>
<td>5.4</td>
<td>11.4</td>
</tr>
<tr>
<td>Restart errors (%)</td>
<td>6.13; ±1.00</td>
<td>6.96</td>
<td>0.27</td>
<td>6.96</td>
</tr>
<tr>
<td>Entries into opposition’s 22-m zone</td>
<td>3.59; ±0.31</td>
<td>1.16</td>
<td>0.87</td>
<td>0.77</td>
</tr>
<tr>
<td>Tries per entry into opposition’s 22-m zone</td>
<td>0.64; ±0.03</td>
<td>0.14</td>
<td>0.09</td>
<td>0.11</td>
</tr>
</tbody>
</table>

\(^{\dagger}\)Values expressed as counts per match unless otherwise indicated; CL = confidence limits; 90% confidence limits: *×/÷1.1 to 1.2, †×/÷1.3 to 3.0, ‡×/÷1.1.

An increase in entries into the opposition’s 22-m zone per match and tries per entry into the opposition’s 22-m zone within a team had a substantial relationship with an improvement in tournament ranking. In contrast, an increase in a team’s mean passes per try from tournament to tournament had a substantial relationship with a worse ranking (Figure 4.1). All other within-team relationships were clearly trivial.
Figure 4.1. Effect of two standard deviations of between-team differences and within-team changes of team performance indicators on ranking in International Rugby Board Sevens World Series tournaments. Performance indicators are expressed as counts per match unless otherwise indicated. A negative difference or change represents a better ranking. Bars are 90% confidence intervals. Dotted lines represent thresholds for smallest meaningful improvement (-20%) and decrement (25%). Where error bars simultaneously cross the negative and positive values of the smallest meaningful difference, the effect is unclear.

More entries into the opposition’s 22-m zone per match, tries per entry into the opposition’s 22-m zone, tackles per match, passes per match, rucks per match and a higher percentage of tackle completion were associated with a better ranking relative to other teams. Conversely, more passes per try, rucks per try, kicks per try, errors per match, surrendered possessions per match, and missed tackles per match were related to a worse tournament ranking (Figure 4.1).
The between-team relationships of percentage of restarts regained, kicks per match, and percentage of restart errors with ranking were unclear.

**Discussion**

Better tournament rankings in international rugby sevens were associated with superior efficiency in attack and technical abilities emphasising the maintenance of ball possession and higher tackle completion. These technical elements provide important information in understanding the tactics associated with successful outcomes in international competition. The analysis of match statistics from the nine tournaments of the men’s 2011/2012 IRB Sevens World Series enabled reference values for team performance indicators to be calculated. Relating the typical differences or changes in these values with tournament rankings informs the preparation of teams for international competition.

The largest positive between-team effects were observed for an increase in passes per try, rucks per try and kicks per try averaged over a tournament. The magnitudes of these effects highlight the importance of attacking proficiency to a team’s overall performance. The most successful teams are more efficient in converting ball possessions into points-scoring movements. For example, a team with 19 more passes per try in a tournament (that is, two between-team means SD) than a team with a final ranking of fourth is likely to have a ranking of ninth (fifth to thirteenth; 90% confidence interval). Similarly, performing 19 more passes per try than the tournament runner-up will likely result in a ranking of fourth (second to sixth).

The mean number of passes per try in this study (17) was markedly higher than for successful (winning rate ≥70%; 7 passes per try) and less successful (11 passes per try) teams in international rugby sevens competition in 2001 [144]. The observed difference may indicate that the patterns of play in the IRB Sevens World Series have changed over time. However, the possibility that contemporary teams adopt a different tactical approach by taking the ball into contact more often, and thus passing less frequently, is not supported by the fact that there were trivial differences between matches in 2001 and 2011/2012 in the frequency of passes or rucks per match. Instead, it appears modern matches are more closely contested, resulting in fewer tries.

The control of ball possession appears a key determinant of IRB Sevens World Series tournament outcomes [144,261]. In 2001, successful teams averaged 51% of possession time per match, whereas less successful teams averaged 43% [144]. It is plausible the negative
between-team relationships between the frequency of rucks, passes and entries into the opposition’s 22-m zone per match and ranking in the present study partially reflect the higher absolute possession time of better-performing teams. Successful teams maintain ball possession by limiting the frequency of errors and turnovers, thereby reducing the opponent’s possession time and attacking opportunities. The mean number of errors per match (3.4) was lower than that reported for successful (8 errors) and less successful (6 errors) teams in 2001 [144]. This difference may indicate an improvement in the technical proficiency and skill of present-day teams, or possibly a difference in definitions used for notational analysis. In the 2001 matches, there was a mean of four handling errors per match, similar to the number of errors per match in the current study. Clearly, reducing the frequency of errors and surrendered possessions through effective skill execution improves a team’s opportunities for scoring points and likelihood of success in a tournament.

As it is not possible to maintain control of the ball for an entire match, better-ranked teams are also more effective in defence. More-successful teams are characterised by a higher number of successful tackles and fewer missed tackles, leading to a higher rate of tackle completion. These findings are in agreement with observations of international matches played in 2001, where the more successful teams performed better in defence than less successful teams [144]. However, in contrast to the present findings, successful teams in 2001 completed less tackles (16 per match) than other teams (19 per match). The lower number of tackles completed by successful teams was explained by their higher proportion of ball possession, which limited the number of tackles required [144]. In the current sample of international matches, teams completed a mean of 15 tackles per match. The difference between the results from 2001 and contemporary matches may be related to methodological differences, sampling variation, or changing patterns of play in international rugby sevens. It is evident that successful teams in international competitions require a combination of skilled individual players capable of effecting tackles and well-organised defensive structures that increase the rate of tackle completion and limit the opposition’s attacking opportunities.

Although most performance indicators demonstrated substantial relationships with tournament outcomes, some indicators were less prominently linked with a team’s overall performance. The frequency of general-play kicks and measures of relative success in restart set-piece plays had unclear associations with tournament ranking. The unclear, and potentially trivial, relationship between these indicators and ranking suggest coaches should prioritise other areas of their teams’ technical development. Tactics that increase
opportunities for maintaining ball possession rather than kicking for territory should also be considered. The number of entries into the opposition’s 22-m zone had the largest beneficial between- and within-team effects on a team’s tournament ranking. Coaches should therefore encourage teams to gain territory by controlling possession. This recommendation is in contrast with observations of international rugby union, where winning teams were more likely to adopt a territory- rather than possession-based approach by kicking the ball more frequently and pressuring the opposition in defence and in set-piece plays [33,195]. The differences in tactics between rugby sevens and rugby union likely result from the greater space available to players in rugby sevens: more space permits teams to create points-scoring passages of play from any field position and somewhat reduces the importance of set-piece plays.

The within-team relationships quantified in this study represent the changes in ranking as a team changes its performance indicators, whereas the between-team relationships characterise the stable differences in rankings associated with differences in indicators between teams from tournament to tournament. By averaging team performances across tournaments to quantify between-team relationships, the attenuating effect of the inherent variability in performance indicator values was reduced, thereby strengthening the observed association with team ranking. The assessment of summary statistics averaged for each team over all matches contested in a tournament is appropriate for identifying the indicators most important for successful competition outcomes, as the tournament format of international events ensures teams play opponents closely matched in ability as they progress beyond the pool stage. Although analyses of averaged tournament statistics provide important information on the team indicator values of successful and unsuccessful teams, it is likely an individual team’s tactical approach, and hence performance indicator values, will vary depending on their playing style and the specific circumstances of each match [246]. Additional research is required on the match-to-match variability in performance indicators and the mostly trivial within-team between-tournament effects observed in this study.

This study was limited to official match statistics routinely collected during the IRB Sevens World Series. Factors such as tournament location, environmental conditions, quality of opposition, and injuries also influence a team’s performance during competition [247]. Despite the omission of these predictor variables from the analyses, the relationships of the selected indicators with individual differences or changes in tournament team ranking demonstrate the relative importance of these indicators to rugby sevens performance. Future
investigations should examine the interaction of other variables that could affect tournament outcomes to inform the technical and tactical preparation of teams for competition.

Quantifying the relationships between individual performance indicators and tournament rankings allows for more objective evaluation and prescription of a team’s technical preparation. However, this analysis does not provide details of the cumulative effect on team ranking when indicators are combined. It is likely that substantial correlations exist between some performance indicators that should be considered when planning a team’s preparation programme or tactical approach to competition. Subsequent studies using similar methodology could investigate competition outcomes and tactical patterns of play, such as the techniques employed by teams to maintain ball possession [47] and score points [249]. A progressive investigation of this nature would further inform coaching and support staff of the tactical and strategic behaviours of successful rugby sevens teams.

**Conclusion**

The analysis of each tournament throughout the entire 2011/2012 IRB Sevens World Series highlights the technical elements of play related to success at the highest level of international rugby sevens. Through the analysis of a large sample of international tournaments, we identified several team performance indicators related to tournament outcomes. The reference values for these indicators should be useful to assess performance and inform team preparation. The findings underscore the importance of effectiveness in offensive and defensive elements of play for success in international competition. To increase the likelihood of success in tournaments, coaches should develop team tactics and the technical abilities of players to maintain ball possession by reducing errors and turnovers, maximise attacking efficiency, and increase the rate of successful tackle completion. These tactics will increase a team’s scoring opportunities and minimise the opponents’ ability to control the ball and score points.

**Practical Implications**

- Successful international rugby sevens teams maintain ball possession by reducing errors and turnovers, are efficient in converting possession into tries, and have effective defensive structures resulting in a high rate of tackle completion.
- Coaches and support staff can use selected performance indicators to evaluate the performance of their team and the opposition, and to plan tactical approaches that enhance tournament outcomes.
Chapter 4 – Relationships between Rugby Sevens Performance Indicators and International Tournament Outcomes

- Technical preparation for international rugby sevens competition should give attention to offence and defence.
- The priorities for a team’s technical development should reflect the magnitudes of the relationships between team performance indicators and tournament ranking.
Chapter Five - Patterns of Play Associated with Success in International Rugby Sevens


**Abstract**

Understanding the relationships between annual mean performance indicators and team ranking in the IRB Sevens World Series should inform long-term tactical approaches to competition. In this study we characterised these relationships using official data for each of the 12 core teams during the men’s IRB Sevens World Series between 2008/2009 and 2011/2012. Mean values, typical within-team variability and typical between-team differences were derived from the four annual World Series mean values for 23 performance indicators. Linear mixed modelling was employed to quantify the effect of an increase in performance indicator values (from typically low to typically high) on logarithmically-transformed series ranking within and between teams. Ten indicators had clear substantial between-team effects (2- to 3-fold differences) on team ranking, but only five had clear substantial within-team effects (~1.5-fold changes). Tries scored and tries conceded had the strongest effects on ranking. Tactics that improved team ranking were based on increasing ball retention in line-outs and the breakdown, turning over possession more frequently in opposition rucks, and pressuring the opposition in their territory by kicking fewer short restarts. These findings confirm the intuitive importance of some common performance indicators and provide valuable novel insights for tactical planning.

**Key words:** statistics, match analysis, notational analysis, performance analysis, performance indicators, rugby union
Introduction
Rugby sevens is an abridged format of rugby union played under substantially the same laws. In contrast to rugby union, a rugby sevens match is contested over 7-min halves by seven players on the field for each team. The increase in worldwide popularity and international competitiveness in rugby sevens, particularly accompanying the announcement of the Olympic Games debut of the sport in 2016, has increased the need for scientific support to enhance performance. Scientific investigations of contemporary rugby sevens have examined the movement patterns [132,134,241] and physiological responses [240,244] of players during competition, and the anthropometric, physical, and physiological characteristics of international-level players [131,133]. These studies provide valuable information to coaches and support staff developing programmes for player selection and physical development that are specific to the demands of competition.

One aspect of rugby sevens competition that has received little scientific inquiry is the tactical component of performance. Technical and tactical performance indicators are regularly quantified in sport to define patterns of play employed by competitors to exploit their perceived strengths and the opposition’s weaknesses in technical proficiency. In team invasion sports such as rugby sevens, these indicators characterise a team’s use of ball possession, field position, fitness, and movement to execute patterns of play. To be useful in informing tactical approaches, performance indicators must be associated with success. Studies of rugby union performance have identified performance indicators that discriminate between winning and losing teams [33,153,195,263,264]. However, equivalent studies are yet to be published for rugby sevens.

Recent research into team performance during the knockout stages of the 2011 Rugby World Cup identified a territory-based strategy as the most effective for match success [33]. This research supports previous findings that winning rugby union teams have greater success at the line-out [153,195,263,264], kick more frequently [195,263,264], miss fewer tackles [195,263], and make more line breaks [75,195] relative to losing teams. Differences in the physical nature of rugby sevens and rugby union [132] imply outcomes of analyses of performance indicators in rugby union may not be directly applicable to rugby sevens. Furthermore, unlike most rugby union competitions which follow a league-style format, usually with a single weekly match, rugby sevens competitions are typically played in a tournament format. International rugby sevens tournaments are generally contested over two
or three successive days with teams playing up to three matches per day. The International Rugby Board (IRB) Sevens World Series is an annual series of international rugby sevens tournaments (rounds) contested by national teams from around the world over an eight-month period. Every year a number of core teams qualify to contest every tournament of the World Series. National rugby sevens teams compete for World Series points at each round, with points awarded based on each team’s finishing position in the tournament. The overall IRB Sevens World Series champion and final team rankings are determined at the end of the World Series based on the points accumulated over each tournament round.

It is likely the expansive nature and tournament format of rugby sevens influences the tactical approaches and performance indicators associated with success. Knowledge of the patterns of play related to success in the IRB Sevens World Series will assist coaches to develop tactical approaches specific to international rugby sevens. Therefore, the purpose of this study was to characterise performance indicators in international rugby sevens competition and quantify the relationships between performance indicators and annual team ranking in the men’s IRB Sevens World Series.

**Methods**

**Sample**

A four-year retrospective longitudinal study design was employed. Summary statistics and annual World Series rankings of the 12 core teams (those who participated in every World Series tournament) from the 2008/2009 to 2011/2012 IRB Sevens World Series were retrieved from the official IRB tournament website (http://www.irbsevens.com). Team performance indicators were classified into four categories: match development, scoring, set-piece play, and phase play (Table 5.1). Match development indicators quantified the time with the ball and number of law infringements for a given team. Scoring indicators described the way and frequency in which points were scored or conceded. Set-piece play indicators described the nature and outcome of line-outs, scrums and restarts. Phase play indicators detailed how the team used the ball when in possession.
Table 5.1. Categories of team performance indicators in rugby sevens.

<table>
<thead>
<tr>
<th>Category</th>
<th>Team performance indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Match development</td>
<td>percentage of ball possession, penalties and free kicks conceded, percentage of all penalties and free kicks awarded to (as opposed to against) the team</td>
</tr>
<tr>
<td>Scoring</td>
<td>tries scored, tries conceded, ball possession time (s) per try scored, opposition ball possession time (s) per try conceded, percentage of successful conversions, percentage of tries scored with no rucks in proceeding passage of play, percentage of tries conceded with no rucks in proceeding passage of play, percentage of tries scored with ≤ three passes in proceeding passage of play</td>
</tr>
<tr>
<td>Set-piece play</td>
<td>percentage of contestable restarts (kicked short), percentage of contestable restarts regained, percentage of scrum possessions retained, percentage of line-out possessions retained</td>
</tr>
<tr>
<td>Phase play</td>
<td>passes, passes per min of possession, percentage of passing movements with ≥ five passes, rucks formed, rucks formed per min of possession, percentage of own rucks won, percentage of opposition rucks won, kicks</td>
</tr>
</tbody>
</table>

Match statistics representing totals over the entire IRB Sevens World Series for each match event for each team were normalised (e.g., percentage or per match) to account for differences in the number of matches contested and match events for each team.

**Statistical Analysis**

Data were imported into the Statistical Analysis System (version 9.3, SAS Institute, Cary, NC). Annual World Series rankings were logarithmically transformed to allow interpretation of percent or factor effects rather than absolute differences in ranking. Analyses of transformed rankings gave estimates of differences in rankings equal relative importance for the best- to worst-ranked teams. For example, the difference between teams finishing second and first is equivalent to the difference between twelfth and eleventh without transformation (one rank improvement) and between twelfth and sixth with transformation (50% improvement). Mixed model analyses with a random effect for team were used to calculate the mean and between- and within-team standard deviations (SD) for team performance indicators and World Series ranking. Mean values were estimated as the intercept, between-team standard deviation calculated from the random effect, and the within-team standard deviation calculated from the residual variance. A standard deviation representing observed typical differences between teams from World Series to World Series was calculated as the
square root of the sum of the between-team and within-team variances. Intraclass correlation coefficients representing series-to-series reliability of ranking and performance indicators were calculated as the between-team variance divided by the observed variance.

A linear mixed model was used to characterise the relationship between the performance indicator and World Series ranking. The model specified the performance indicator as a fixed effect, team as a random effect, and an interaction effect for performance indicator and team. This model allowed for potential individual team differences in the relationship between the performance indicator and ranking. A linear association between performance indicators and ranking was deemed most appropriate after evaluation of a quadratic trend produced no additional meaningful information. A linear relationship also permitted simpler interpretation of effects. The effect of a change from series to series within a team in performance indicator value on ranking was assessed by multiplying the slope of the relationship by two within-team standard deviations [141]. Two standard deviations represent the change within a team from a typically low performance indicator value (-1 SD) to a typically high value (+1 SD).

A between-team effect of the team indicators was estimated by averaging the values of the performance indicator and ranking between the 2008/2009 and 2011/2012 World Series for each of the 12 teams. The effect of the performance indicator was derived by multiplying the slope of the linear relationship between the means by twice the standard deviation of the teams' mean values of the performance indicator. A two standard deviation increase represented the typical difference between teams from World Series to World Series.

Inferences about effects of performance indicators were assessed using the smallest meaningful difference in World Series ranking. From the 2012/2013 men’s IRB Sevens World Series the number of core teams was increased from 12 to 15 and a promotion and relegation system introduced. Based on this change, the smallest meaningful improvement in annual ranking was defined as 20% (a factor difference of 0.8 of the original ranking). This improvement in ranking represents the difference required to move a team from fifteenth (bottom rank) to twelfth, out of the bottom three teams at risk of relegation and who must re-qualify for core team status. The equal and opposite smallest meaningful decrement was defined by a 25% worse ranking (a factor difference of 1/0.8 or 1.25). An inference about the true value of an effect was based on the uncertainty of its magnitude. When the 90% confidence interval concurrently crossed the thresholds for the smallest meaningful decrement and improvement, the effect was deemed unclear [141].
Results

The centrality and dispersion of World Series ranking (in raw units) and match development, scoring, set-piece play, and phase play performance indicators are summarised by the mean and observed standard deviation (Table 5.2). The observed standard deviation is composed of the between-team standard deviation, representing the stable typical differences between teams, and the within-team standard deviation, representing the typical variability of a team between World Series. The observed (×/÷2.10), between-team (×/÷1.80), and within-team (×/÷1.57) standard deviations of log-transformed World Series ranking were also calculated and expressed as a factor. The intraclass reliability correlation coefficients, corresponding to the proportion of variance in performance indicators accounted for by between-team differences, ranged from 0.00 to 0.82 (Table 5.2). The intraclass correlation coefficient of log-transformed World Series ranking was 0.63.
Table 5.2. Rugby sevens annual team ranking and annual team mean performance indicators, expressed as averaged counts per match unless otherwise stated, in the International Rugby Board Sevens World Series (n = 12 teams in four series between 2008/2009 and 2011/2012).

<table>
<thead>
<tr>
<th></th>
<th>Mean*</th>
<th>Observed SD</th>
<th>Between-team SD</th>
<th>Within-team SD</th>
<th>ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual ranking (raw units)</td>
<td>6.5</td>
<td>3.5</td>
<td>3.1</td>
<td>1.7</td>
<td>0.73</td>
</tr>
<tr>
<td>Match development</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ball possession (%)</td>
<td>51.2</td>
<td>2.6</td>
<td>1.8</td>
<td>1.8</td>
<td>0.52</td>
</tr>
<tr>
<td>Penalties/free kicks conceded</td>
<td>2.86</td>
<td>0.33</td>
<td>0.12</td>
<td>0.31</td>
<td>0.12</td>
</tr>
<tr>
<td>Penalties/free kicks awarded to team (%)</td>
<td>50.6</td>
<td>4.9</td>
<td>3.6</td>
<td>3.3</td>
<td>0.55</td>
</tr>
<tr>
<td>Scoring</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tries scored</td>
<td>3.19</td>
<td>0.68</td>
<td>0.61</td>
<td>0.30</td>
<td>0.81</td>
</tr>
<tr>
<td>Tries conceded</td>
<td>2.48</td>
<td>0.55</td>
<td>0.50</td>
<td>0.23</td>
<td>0.82</td>
</tr>
<tr>
<td>Possession time per try scored (s)</td>
<td>72</td>
<td>15</td>
<td>13</td>
<td>8</td>
<td>0.70</td>
</tr>
<tr>
<td>Opposition possession time per try conceded (s)</td>
<td>90</td>
<td>24</td>
<td>22</td>
<td>11</td>
<td>0.81</td>
</tr>
<tr>
<td>Successful conversions (%)</td>
<td>63.2</td>
<td>5.8</td>
<td>3.6</td>
<td>4.6</td>
<td>0.38</td>
</tr>
<tr>
<td>Tries scored with no ruck (%)</td>
<td>60.8</td>
<td>9.4</td>
<td>1.5</td>
<td>9.3</td>
<td>0.03</td>
</tr>
<tr>
<td>Tries conceded with no ruck (%)</td>
<td>60.9</td>
<td>9.9</td>
<td>0.0</td>
<td>9.9</td>
<td>0.00</td>
</tr>
<tr>
<td>Tries scored with ≤ three passes (%)</td>
<td>53.1</td>
<td>5.6</td>
<td>2.1</td>
<td>5.2</td>
<td>0.14</td>
</tr>
<tr>
<td>Set-piece play</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contestable restarts (%)</td>
<td>74.5</td>
<td>11.3</td>
<td>7.7</td>
<td>8.3</td>
<td>0.46</td>
</tr>
<tr>
<td>Contestable restarts regained (%)</td>
<td>35.9</td>
<td>5.8</td>
<td>3.9</td>
<td>4.2</td>
<td>0.46</td>
</tr>
<tr>
<td>Scrum possessions retained (%)</td>
<td>89.8</td>
<td>5.7</td>
<td>0.0</td>
<td>5.7</td>
<td>0.00</td>
</tr>
<tr>
<td>Line-out possessions retained (%)</td>
<td>77.4</td>
<td>8.1</td>
<td>3.6</td>
<td>7.3</td>
<td>0.19</td>
</tr>
<tr>
<td>Phase play</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passes</td>
<td>35.5</td>
<td>3.6</td>
<td>1.9</td>
<td>3.0</td>
<td>0.27</td>
</tr>
<tr>
<td>Passes per min of possession</td>
<td>9.63</td>
<td>0.71</td>
<td>0.43</td>
<td>0.56</td>
<td>0.37</td>
</tr>
<tr>
<td>Passing movements with ≥ five passes (%)</td>
<td>12.4</td>
<td>4.5</td>
<td>3.4</td>
<td>3.0</td>
<td>0.57</td>
</tr>
<tr>
<td>Rucks formed</td>
<td>9.11</td>
<td>1.87</td>
<td>1.35</td>
<td>1.29</td>
<td>0.52</td>
</tr>
<tr>
<td>Rucks per min of possession</td>
<td>2.49</td>
<td>0.45</td>
<td>0.34</td>
<td>0.29</td>
<td>0.59</td>
</tr>
<tr>
<td>Own rucks won (%)</td>
<td>83.7</td>
<td>3.7</td>
<td>1.3</td>
<td>3.5</td>
<td>0.12</td>
</tr>
<tr>
<td>Opposition rucks won (%)</td>
<td>17.5</td>
<td>3.8</td>
<td>1.1</td>
<td>3.7</td>
<td>0.08</td>
</tr>
<tr>
<td>Kicks</td>
<td>1.58</td>
<td>0.82</td>
<td>0.41</td>
<td>0.71</td>
<td>0.24</td>
</tr>
</tbody>
</table>

90% confidence limits (×/÷) 1.2-1.4 1.5-10.7 1.2-1.3

*90% confidence limits: mean ± 0.3 to 0.5 × observed SD
ICC = intraclass correlation coefficient.

A higher number of passes and tries conceded, and increased possession time per try scored within a team between World Series were related to a worse ranking (~1.4-fold decrement), whereas higher opposition possession time per try conceded and more tries scored were related to an improvement in World Series ranking (~1.6-fold improvement) (Figure 5.1). All other within-team effects were unclear or trivial (within the thresholds for the smallest meaningful difference). More tries scored, penalties and free kicks conceded, and a higher opposition possession time per try conceded, percentage of own rucks won, percentage of opposition rucks won, and percentage of line-out possessions retained were related to a better
ranking than other teams (~2.1- to 3.4-fold improvement). Conversely, more tries conceded and a higher possession time per try scored, percentage of contestable restarts and percentage of tries conceded with no ruck than other teams were related to a worse ranking (~1.8- to 3.3-fold decrement) (Figure 5.1). Between-team effects were either unclear or trivial for rucks, rucks per min of possession, percentage of penalties and free kicks awarded to a team, kicks, passes per min of possession, percentage of possession, percentage of scrum possessions retained, percentage of passing movements with ≥ five passes, percentage of contestable restarts regained, percentage of successful conversions, percentage of tries scored with no ruck, and percentage of tries scored with ≤ three passes.

![Figure 5.1](image-url)

Figure 5.1. Effect of two standard deviations of within-team changes and between-team differences of team performance indicators on annual ranking in the International Rugby Board Sevens World Series. Performance indicators are expressed as mean counts per match unless otherwise indicated. A negative difference or change represents a better ranking. Bars are 90% confidence intervals. Shaded region represents a trivial effect between the thresholds for smallest meaningful improvement.
(-20%) and decrement (25%). The effect is unclear where error bars simultaneously cross the negative and positive values of the smallest meaningful difference.

Discussion
This study provides important insights into the patterns of play associated with relative team performance outcomes in international rugby sevens. Unsurprisingly, the mean number of tries scored and conceded by a team best discriminated higher and lower World Series rankings within and between teams. Moreover, when averaged over all matches of the World Series, the most successful teams were those that gained and maintained ball possession by dominating the ruck contest and retaining line-out possession. Better-ranked teams also tended to concede more penalties and free kicks and kick fewer short, contestable restarts. The study’s findings provide practical information on the key performance indicators associated with success most important for longitudinal monitoring and comparison. Characterisation of performance indicators from multiple teams during four consecutive IRB Sevens World Series should be useful for evaluating team performances, establishing match objectives and planning training programmes.

Aside from supporting the construct validity of the analyses used, whereby the model actually represents the relationships being investigated, the finding that better-performing teams score more and concede fewer tries is intuitive, given 344 (88%) of the 392 matches contested in the 2011/2012 IRB Sevens World Series were won by the team that scored most tries [149]. This investigation adds to the knowledge of patterns of play in rugby sevens by describing the collective behaviours of successful and less-successful teams. Specifically, the findings offer information on the tactics employed by successful teams to score more frequently than their opponents. Although differences between teams may not be clearly evident in any individual match, when match statistics are averaged over the entire World Series, substantial disparities emerge between teams in their technical ability and tactical focus associated with their annual World Series ranking.

The mean percentage of ball possession time in a match had an unclear effect on ranking between teams and a trivial effect within teams. Instead, better-ranked teams were more effective in converting possessions into points-scoring movements as well as restricting tries being scored when their opponents had possession. A two standard deviation difference between teams in percentage of opposition rucks won was related to a 60% improvement in World Series ranking, indicating more-successful teams were also effective in capitalising on
turnovers in possession. For example, a team winning 4.4% more opposition rucks than a team with a final World Series ranking of eighth would typically finish with a ranking of third (second to fifth, 90% confidence interval). Turning over ball possession from the opposition at the breakdown markedly increases a team’s scoring opportunity by allowing a team to attack when their opponents are vulnerable in the transition from offence to defence.

Better-ranked teams were not only dominant in attack, but also proficient in defence. More-successful teams conceded fewer tries per match and had a lower proportion of tries scored against them with no ruck in the preceding phase. It appears the defensive systems of successful teams are central in conceding tries less frequently and easily than their opponents and exerting greater dominance in contact situations. Given the greater relative space available to players in rugby sevens compared with rugby union, effective tackling and defensive structures enable the most successful teams to more readily transform an opposition’s breakdown into an attacking opportunity.

Although the number of scrums and line-outs in a rugby sevens match is typically lower than in a rugby union match [207], there are substantial differences between higher- and lower-ranked rugby sevens teams in their tactics and technical proficiency during set-piece plays. Both scrums and line-outs in rugby sevens matches were most frequently won by the team feeding or throwing the ball in. However, the proportion of line-out possessions retained (77%) was lower than for scrums (90%). Over an entire World Series, better-ranked teams retained possession in line-outs more frequently than worse-ranked teams, with the magnitude of the effect on a team’s ranking similar to that of percentage of own rucks won.

The line-out provides an attacking platform by the off-side distance enforced between the attacking and defending teams. During the 2011/2012 IRB Sevens World Series, 9% of all tries originated from line-out possessions [149]. Evidently, more frequently retaining ball possession at the line-out increases a team’s attacking opportunities. Conversely, by increasing the proportion of opposition line-outs won, a team’s prospects of gaining territory and scoring are increased because the opposition back-line players are in a weak position as they adjust from an offensive to defensive structure. Winning possession of the ball from the opponent’s lineout simultaneously reduces the opposition’s opportunity to attack and score points.

The importance of the restart set-piece in deciding match outcomes cannot be underestimated, given one fifth of all tries in the 2011/2012 IRB Sevens World Series
Chapter 5 – Patterns of Play Associated with Success in International Rugby Sevens

originated from restarts [149]. Although the results trended toward an improvement in World Series ranking, a higher proportion of contestable restarts regained had an unclear effect between teams and a clear trivial effect within teams. Better-performing teams more frequently chose longer restart kicks over shorter, contestable kicks landing closer to the half-way line. It appears successful teams more often choose to kick longer at the restart to gain a territorial advantage and pressure the opposition with strong defence, even if it means conceding possession of the ball. It is also plausible longer kicks may reduce the potential for errors at the restart. However, this assertion requires further empirical investigation.

A higher number of penalties and free kicks conceded relative to other teams was associated with a better World Series ranking. Although a purported relationship between poorer discipline and team performance is somewhat counterintuitive, it supports observations contrasting successful (winning rate ≥70%) and less-successful teams during international matches played in 2001 [144]. The disparity in the number of penalties and free kicks conceded by successful and unsuccessful teams may be explained by better-performing teams being more likely to utilise the advantage rule. In this case, even though a law infringement is committed by the opposition, a penalty is not awarded as the team in possession chooses to continue play. Further investigation of how and when teams concede penalties and free kicks is required. Indeed, it is possible more-successful teams tend to concede more penalties at the breakdown. Such an outcome might reflect a risk-reward trade-off as teams try to dominate the breakdown in search of a turnover in possession.

It is likely a variety of playing styles and tactical approaches are employed by different teams, or even the same team against different opponents, all of which may be effective based on the technical strengths and weaknesses of the competing teams. The current method of analysing a large sample of matches over several teams and years is valuable in identifying common tendencies and patterns of successful teams. Averaging team performances over the entire World Series is also robust in compensating for variations in match location, environmental conditions, officiating styles and other factors that can influence a team’s performance [247]. However, it is acknowledged that averaging performance indicators over several matches makes it impossible to distinguish variations in team performances during individual matches [246]. Practitioners working with a specific team could adopt a case-study design to quantify the longitudinal effects of particular strategies and tactics on performance. For almost all of the performance indicators investigated, the magnitude of the association with World Series ranking was larger between teams than within teams. At the same time, the
intraclass correlation coefficients were largest for indicators most associated with a team’s ranking (e.g., tries scored or conceded, possession time per try scored and opposition possession time per try conceded). These performance indicators therefore had the largest between-team differences relative to the magnitude of within-team changes from series to series. This circumstance partially explains the discrepancy between within- and between-team effects and the reason teams usually have only a small to moderate change in their ranking from series to series.

This study was limited to routinely-collected official match statistics summarised over all matches played by each team during the IRB Sevens World Series. Future research may identify additional performance indicators associated with success in international rugby sevens competition. Findings from analyses of other indicators representing offensive and defensive patterns of play may be useful in preparing teams and planning strategies employed in tournaments. Despite encompassing four World Series between 2008/2009 and 2011/2012, the current data set was relatively limited in size, especially in regard to examining between-team relationships. The small sample size yielded many unclear between-team effects with relatively large uncertainty in relationships. Given official match statistics were not available for World Series prior to 2008/2009, the inclusion of observations from World Series after 2011/2012 would reduce the magnitude of uncertainty, likely resulting in more performance indicators becoming clear in their association with an improvement or decrement in a team’s World Series ranking.

**Conclusion**

The analysis of match statistics from four years of the IRB Sevens World Series characterised the within- and between-team variability in patterns of play. Based on the typical differences between and changes within teams, several indicators discriminated between successful and less-successful team performances. These performance indicators may be applied to monitor and compare team performances and should assist coaches in developing strategies that enhance a team’s probability of success in international competition. To improve a team’s ranking in the IRB Sevens World Series, tactics should be based on scoring more and conceding fewer tries by increasing ball retention in line-outs and at the breakdown, turning the ball over more frequently in opposition rucks, and pressuring the opposition in their territory by kicking fewer contestable restarts.
Chapter Six - Movement Patterns in Rugby Sevens: Effects of Tournament Level, Fatigue and Substitute Players


Abstract

*Objective*: Understanding of the physical demands and the effects of fatigue and substitute players in rugby sevens is limited. This study quantified the differences in movement patterns between domestic and international rugby sevens tournaments, the effects of fatigue within and between matches during tournaments, and movement patterns of second half substitute players.

*Design*: Movement patterns of 19 international-level male rugby sevens players were recorded using a Global Positioning System (GPS) device during 11 international and 16 domestic matches (n = 174 files).

*Methods*: Maximum velocity, total distance covered, distance covered in velocity zones and number of moderate and high accelerations and decelerations are reported per min of match time. Movement patterns were compared between international and domestic matches, first and second half, first and last tournament match and substitute and full-match players.

*Results*: Substantially greater distance was covered at high velocity (~27% at ≥6 m·s\(^{-1}\)) and 4 to 39% more accelerations and decelerations were performed in international than domestic matches. The relative distance covered by players at velocities >2 m·s\(^{-1}\) and the number of changes in velocity were reduced by 1 to 16% from first to second half. Small differences were observed in activity at <5 m·s\(^{-1}\) (-8 to 8%) and moderate accelerations (-18%) from first to last tournament match. All movement variables were higher (2 to 123%) for substitute players.
**Conclusions:** International rugby sevens competition is more intense than domestic matches. Despite reductions in work-rate within individual matches, there is little indication of accumulated fatigue over a multi-day tournament.

**Key words:** GPS, time-motion analysis, game analysis, acceleration, sprint


Chapter 6 – Movement Patterns in Rugby Sevens: Effects of Tournament Level, Fatigue and Substitute Players

Introduction
The popularity of rugby sevens has spread rapidly in recent years and the sport is now played at the domestic and international level all over the world. In 2009, rugby sevens was formally included in the Olympic Games from 2016. Rugby sevens is an abbreviated variant of rugby union in which two teams, each with seven players on the field, compete for 7-min halves with a 2-min half-time interval. Rugby sevens is played on a full dimension rugby union field under substantially the same laws as 15-player rugby union. Given the increasing number of international competitions in rugby sevens, the transition from the domestic to international stage is an important consideration for players and coaches, yet to date, there is no scientific review of the likely differences in game demands between international- and domestic-level competition.

Rugby sevens competitions differ from 15-player rugby union in that they are usually played over 2- or sometimes 3-day tournaments. Teams play three group stage matches on day one and two, typically with ~3 h between matches and then, depending on results, up to three finals matches on the last day. The ability of players to repeat short-duration, high-intensity running efforts on multiple occasions over several days and changes in movement patterns over the duration of a tournament have not been previously examined. The use of tactical player substitutions in the latter stages of a match is a strategy often adopted by coaches to mitigate the potential effect of fatigue in reducing individual and team performance. However, the work-rate contribution of substitute players in rugby sevens is unknown.

Only one previous study has examined the movement patterns of players during rugby sevens competition [216]. This study was conducted during a tournament in 1996 and its relevance to the modern game is limited by changing game demands and player characteristics observed in rugby union over recent years [78,98]. Furthermore, the introduction of new measurement and analysis techniques such as Global Positioning System (GPS) technology now allows for the velocity and distances covered by players to be quantified [151,199]. Understanding the movement patterns of rugby sevens will assist coaches prescribing and implementing sport-specific training programmes that replicate the physical demands of competition. The aims of this study were to use GPS technology to: (i) quantify the differences in movement patterns between domestic and international tournaments; (ii) quantify changes in movement patterns within and between matches during tournaments to
examine the effects of player fatigue; and (iii) assess the movement patterns of second half substitute players.

**Methods**

A prospective, observational, longitudinal study design was used to assess the movement patterns of 19 international-level male rugby sevens players (age 21.2 ± 2.7 years; body mass 89.7 ± 7.3 kg; height 1.81 ± 0.05 m; mean ± SD) during 16 matches played over three domestic tournaments and 11 matches played over two international (International Rugby Board World Series) tournaments. Written informed consent was obtained from all players. The study was approved by the University of Canberra Committee for Ethics in Human Research and Australian Institute of Sport Ethics Committee.

The international tournaments were in Adelaide, Australia and Wellington, New Zealand in the Southern Hemisphere summer and autumn months. The domestic Australian tournaments were played in Central Coast, Gold Coast and Darwin during the spring and summer months. Domestic tournaments were sanctioned by the Australian Rugby Union but not part of a formal series. These tournaments were contested for prize money by teams comprising amateur through to semi-professional players and officiated by local referees. Typically teams arrive ~4 days before an international tournament and undertake one or two training sessions each day. For domestic tournaments, most teams arrive 1 to 2 days before commencement and also undertake a light training session per day. All matches were played on standard outdoor natural grass fields.

Movement patterns were assessed by fitting players with a MinimaxX GPS device (Team Sport version 2.5, Catapult Innovations, Melbourne, Australia) recording at 5 Hz. The standard error of the estimate (validity) of distance covered at <2 to 5 m·s⁻¹ for these units ranges from 1.7 to 3.8% and coefficient of variation (CV, reliability) from 1.2 to 2.6% [199]. For a 20-m sprint, the estimate for validity is 17% and 23% for reliability [151]. The GPS device was positioned between the scapulae of the player using an elasticised harness worn underneath the playing attire. The device was activated and satellite lock established for a minimum of 15 min before the commencement of each match. Data were downloaded and analysed using Logan Plus 4.4.0 software (Catapult Innovations, Melbourne, Australia). Movement patterns were quantified based on distance covered in specific velocity zones (0 to 2 m·s⁻¹, 2 to 3.5 m·s⁻¹, 3.5 to 5 m·s⁻¹, 5 to 6 m·s⁻¹ and ≥6 m·s⁻¹), maximum instantaneous velocity and an acceleration/deceleration profile. The chosen velocity zones represent the
range of locomotor activity profiles typical of intermittent team sport and are routinely used during GPS monitoring in Australian rugby union. Acceleration and deceleration characteristics were assessed by the number of times a player performed a moderate (2 to 4 m/s²) or high (>4 m/s²) acceleration or deceleration (moderate -4 to -2 m/s² and high < -4 m/s²) for a minimum duration of 0.4 s. Matches were categorised based on the tournament level (domestic or international) and the order of match played within the tournament (first or last). The effect of player substitutions on movement patterns was assessed by comparing the second half measures of players that played the entire match with those that played less than 4 min. The half-time interval, any time a player spent off the field and stoppage time were excluded from analyses. A total of 174 match files were included for analysis.

Data were log-transformed prior to analysis to reduce the non-uniformity of error and back-transformed to obtain differences in means and variation as percents. Descriptive statistics (mean ± SD) were used to characterise movement patterns. Data are expressed relative to game time played (per min) to account for variations in playing time from match to match and for player substitutions. Magnitude-based inferences on differences within and between tournaments were made by standardising differences using the between-player SD. Precision of estimates are indicated with 90% confidence limits (CL). Magnitudes of standardised effects were assessed as 0 to 0.2 being trivial, 0.2 to 0.6 small, 0.6 to 1.2 moderate, 1.2 to 2.0 large, and >2.0 very large [22]. The effect was reported as unclear when the confidence interval of the standardised difference crossed the threshold for both substantially positive (0.2) and negative (-0.2) values. The CV expressed as a percent was calculated to characterise the variability of movement pattern parameters.

**Results**

Substantial differences between movement patterns during international and domestic tournament matches were observed for all variables with the exception of total distance covered per min (Table 6.1). Players reached a ~6% higher maximum running velocity during international tournament matches than during domestic tournaments and covered 16% and 27% greater distance at 5 to 6 and ≥6 m·s⁻¹, respectively. Similarly, players covered less distance at lower velocity (2 to 5 m·s⁻¹) and performed 4 to 39% more moderate and high accelerations and decelerations per min of play in international competition.
A small decrease was observed in a number of movement pattern variables from the first to second half in 71 full-match files (Table 6.2). Relative to the first half, players exhibited a 5% reduction in total distance covered per min, and a 14% and 16% decline in the number of moderate and high accelerations per min in the second half, respectively. However, the maximum velocity attained by players was maintained between halves.
Table 6.2. First and second half movement patterns of players that contested a full match.

<table>
<thead>
<tr>
<th></th>
<th>1st Half (n = 71)</th>
<th>2nd Half (n = 71)</th>
<th>% change; ±90% CL</th>
<th>Standardised change; ±90% CL</th>
<th>Qualitative outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative distance (m·min⁻¹)</td>
<td>120 ± 19</td>
<td>113 ± 16</td>
<td>-5.3; ±4.2</td>
<td>-0.37; ±0.28</td>
<td>Small -</td>
</tr>
<tr>
<td>Max. velocity (m·s⁻¹)</td>
<td>7.9 ± 1.1</td>
<td>7.9 ± 1.2</td>
<td>0.2; ±4.0</td>
<td>0.01; ±0.28</td>
<td>Unclear</td>
</tr>
<tr>
<td>≥6 m·s⁻¹ m·min⁻¹</td>
<td>10.7 ± 6.9</td>
<td>9.5 ± 6.0</td>
<td>-7; ±23</td>
<td>-0.09; ±0.28</td>
<td>Unclear</td>
</tr>
<tr>
<td>5 to 6 m·s⁻¹ m·min⁻¹</td>
<td>9.9 ± 4.5</td>
<td>9.0 ± 3.8</td>
<td>-10; ±15</td>
<td>-0.22; ±0.28</td>
<td>Small -</td>
</tr>
<tr>
<td>3.5 to 5 m·s⁻¹ m·min⁻¹</td>
<td>24.8 ± 7.1</td>
<td>22.9 ± 6.2</td>
<td>-7.7; ±8.5</td>
<td>-0.27; ±0.28</td>
<td>Small -</td>
</tr>
<tr>
<td>2 to 3.5 m·s⁻¹ m·min⁻¹</td>
<td>33.0 ± 7.8</td>
<td>30.3 ± 7.8</td>
<td>-8.8; ±7.4</td>
<td>-0.36; ±0.28</td>
<td>Small -</td>
</tr>
<tr>
<td>0 to 2 m·s⁻¹ m·min⁻¹</td>
<td>41.3 ± 8.1</td>
<td>41.6 ± 6.0</td>
<td>1.5; ±4.9</td>
<td>0.09; ±0.28</td>
<td>Trivial +</td>
</tr>
<tr>
<td>Moderate accelerations·min⁻¹</td>
<td>1.0 ± 0.4</td>
<td>0.9 ± 0.5</td>
<td>-14; ±15</td>
<td>-0.30; ±0.28</td>
<td>Small -</td>
</tr>
<tr>
<td>High accelerations·min⁻¹</td>
<td>0.4 ± 0.3</td>
<td>0.4 ± 0.3</td>
<td>-16; ±21</td>
<td>-0.27; ±0.29</td>
<td>Small -</td>
</tr>
<tr>
<td>Moderate decelerations·min⁻¹</td>
<td>1.3 ± 0.5</td>
<td>1.3 ± 0.5</td>
<td>-1; ±14</td>
<td>-0.03; ±0.28</td>
<td>Unclear</td>
</tr>
<tr>
<td>High decelerations·min⁻¹</td>
<td>0.3 ± 0.2</td>
<td>0.3 ± 0.2</td>
<td>-13; ±19</td>
<td>-0.23; ±0.29</td>
<td>Small -</td>
</tr>
</tbody>
</table>

+ or - indicates an increase or decrease from the first to second half, respectively. Moderate accelerations and decelerations were defined as a change in velocity between 2 and -4 to -2 m·s⁻², respectively. High accelerations and decelerations were defined as a change in velocity >4 and < -4 m·s⁻², respectively. n = number of match files; CL = confidence limits.

Movement patterns were relatively stable from match to match for the duration of a tournament. When movement patterns were compared between the first and last match of a tournament, that is, the first pool match on day one (n = 39 match files) and the last knockout finals match played on day two (corresponding to either match five or six; n = 29 match files), there was a small 8; ±13% (mean; ±90% CL) increase (0.25; ±0.40 standardised difference) in distance covered per min at 3.5 to 5 m·s⁻¹, a small 4.6; ±8.2% increase (0.23; ±0.40) at 2 to 3.5 m·s⁻¹, a small 8.4; ±6.4% decrease (-0.58; ±0.41) at 0 to 2 m·s⁻¹, and a small 18; ±21% decrease (-0.42; ±0.41) in moderate accelerations per min. The difference in all other movement pattern parameters was unclear.

Second-half substitute players played only 3:01 ± 0:44 min:s (mean ± SD) but exhibited a substantially greater work-rate compared with players that played the entire match (Table 6.3). The largest effects of substitutes were observed for distance covered per min (24%
greater), distance covered at 5 to 6 and ≥6 m·s⁻¹ (110% and 123% greater, respectively), moderate and high accelerations (74% and 85% greater, respectively) and high decelerations (89% greater).

Table 6.3. Second half movement patterns of players that contested a full match and substitute players on the field for less than 4 min.

<table>
<thead>
<tr>
<th></th>
<th>Full Match</th>
<th>Substitute</th>
<th>% difference; ±90% CL</th>
<th>Standardised difference; ±90% CL</th>
<th>Qualitative outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative distance (m·min⁻¹)</td>
<td>113 ± 16</td>
<td>140 ± 14</td>
<td>24; ±6</td>
<td>1.69; ±0.47</td>
<td>Large +</td>
</tr>
<tr>
<td>Max. velocity (m·s⁻¹)</td>
<td>7.9 ± 1.2</td>
<td>8.1 ± 1.4</td>
<td>1.8; ±9.6</td>
<td>0.11; ±0.57</td>
<td>Unclear</td>
</tr>
<tr>
<td>≥6 m·s⁻¹·min⁻¹</td>
<td>9.5 ± 6.0</td>
<td>20.8 ± 12.6</td>
<td>123; ±43</td>
<td>1.16; ±0.51</td>
<td>Moderate +</td>
</tr>
<tr>
<td>5 to 6 m·s⁻¹·min⁻¹</td>
<td>9.0 ± 3.8</td>
<td>17.7 ± 5.8</td>
<td>110; ±21</td>
<td>1.75; ±0.44</td>
<td>Large +</td>
</tr>
<tr>
<td>3.5 to 5 m·s⁻¹·min⁻¹</td>
<td>22.9 ± 6.2</td>
<td>26.1 ± 7.8</td>
<td>14; ±18</td>
<td>0.43; ±0.54</td>
<td>Small +</td>
</tr>
<tr>
<td>2 to 3.5 m·s⁻¹·min⁻¹</td>
<td>30.3 ± 7.8</td>
<td>31.2 ± 8.9</td>
<td>3; ±17</td>
<td>0.10; ±0.55</td>
<td>Unclear</td>
</tr>
<tr>
<td>0 to 2 m·s⁻¹·min⁻¹</td>
<td>41.6 ± 6.0</td>
<td>44.4 ± 7.5</td>
<td>6.3; ±9.6</td>
<td>0.38; ±0.57</td>
<td>Small +</td>
</tr>
<tr>
<td>Moderate accelerations·min⁻¹</td>
<td>0.9 ± 0.5</td>
<td>1.4 ± 0.4</td>
<td>74; ±20</td>
<td>1.24; ±0.41</td>
<td>Large +</td>
</tr>
<tr>
<td>High accelerations·min⁻¹</td>
<td>0.4 ± 0.3</td>
<td>0.5 ± 0.4</td>
<td>85; ±42</td>
<td>0.95; ±0.54</td>
<td>Moderate +</td>
</tr>
<tr>
<td>Moderate decelerations·min⁻¹</td>
<td>1.3 ± 0.5</td>
<td>1.6 ± 1.0</td>
<td>28; ±45</td>
<td>0.42; ±0.64</td>
<td>Unclear</td>
</tr>
<tr>
<td>High decelerations·min⁻¹</td>
<td>0.3 ± 0.2</td>
<td>0.3 ± 0.3</td>
<td>89; ±27</td>
<td>1.28; ±0.48</td>
<td>Large +</td>
</tr>
</tbody>
</table>

+ indicates an increase in substitutes over full-match players. Moderate accelerations and decelerations were defined as a change in velocity between 2 to 4 and -2 to -4 m·s⁻², respectively. High accelerations and decelerations were defined as a change in velocity >4 and < -4 m·s⁻², respectively. n = number of match files; CL = confidence limits.

The CV across all 174 match files for total distance covered per min and maximum velocity were 14%. Variability of relative distance covered increased with movement velocity from 15% at 0 to 2 m·s⁻¹ to 62% at ≥6 m·s⁻¹. High accelerations (CV = 68%) and decelerations (58%) were more variable than moderate accelerations (43%) and decelerations (42%), which had similar variability.

Discussion
This is the first study to characterise the running movement patterns of players during rugby sevens competition using GPS technology. Unsurprisingly, as a result of the modified laws,
rugby sevens is played at a substantially greater running intensity than 15-player rugby union. Compared with GPS data collected with 1-Hz devices during an 83 min professional rugby union match, the current group of rugby sevens players covered ~45% greater total distance per min with a higher proportion of that distance at high velocity (~135% greater distance covered per min at >5 m·s⁻¹) [68]. Although comparisons cannot be made regarding the relative demands of contact situations (tackles, rucks, mauls), the increase in relative running intensity and volume observed in rugby sevens has implications for the physiological requirements and preparation of players wishing to transfer between the two formats.

Substantial differences in movement patterns were observed during different levels of competition, within and between matches and for substitute players. International tournament matches are played at a higher intensity and elicit a greater physical load than domestic matches. Although movement patterns are likely influenced by other factors not measured in the current study such as the opposition’s ability or tactics, international matches required a higher maximum velocity, greater distances covered at high velocity, and a greater number of changes in velocity. Players competing at the international level are likely to have superior physical capacities and skill levels to lower-level players which may, at least partially, explain the observed increase in match intensity. To optimise the physical preparation of players, coaches should prescribe training appropriate to the increased demands of international competition. For example, training drills should include relatively high running loads incorporating changes in velocity and intermittent maximal or near-maximal sprint efforts. A schedule of multiple short-duration, high-intensity training sessions on the same day with limited recovery periods between each may be a useful form of training to increase the specificity of preparation for the tournament-style competitions. Participation in domestic tournaments may have limitations as a sole method of preparing and selecting players to be competitive in international competition.

In agreement with the trend previously observed in rugby sevens and in other elite team sport athletes, players that contested the entire match demonstrated a decreased work-rate from the first to second half [11,209,216]. The mechanisms underlying the small decrement in work-rate are likely to be multifarious and were not examined in the current study. Changes in movement patterns may be related to central [248] and peripheral [158] factors of fatigue or to team tactics. However, the inability of players to sustain high intensity activity over the duration of a match suggests fatigue is an important consideration in performance. Player fatigue may also be a contributing factor in the higher incidence of injuries reported during
the second half of international rugby sevens matches [98]. It is likely that endurance and fatigue resistance are principal physiological attributes of top performing rugby sevens players. Players at higher levels of competition exhibit superior anaerobic and aerobic endurance capacity in a number of team sports [20,181]. Further investigation is needed to confirm the relationship between physical characteristics and playing level in rugby sevens players.

The use of substitute players appears efficacious as a tactical means of maintaining team work-rate. Under the laws of the game, once substituted, a player cannot re-join the match unless replacing a player with a bleeding or open wound. Despite the small number of match files available for analysis, large increases in work-rate variables were observed for second half substitutes compared with players on the field for the entire match. Substitutes covered 24% more distance per min at a higher velocity and with a greater number of changes in velocity. Higher substitute player work-rate is in accordance with previous observations in elite soccer [43,181]. Interestingly, late-game substitute players exhibited a greater work-rate than in the first half of players that contested the full match. These data suggest players may be pacing their activity during the early stages of a match to mitigate fatigue later in the match. This moderation of work-rate occurs despite players not knowing the exact duration of each match or whether they may play the full match. Team sport athletes’ self-regulation of activity is an area that requires further investigation. Nonetheless, it is clear that the replacement of one or more players at a key stage of a match could potentially influence the match result. Additional research is required to optimise the involvement of substitute players and examine whether the contribution of substitutes in the latter stages of a match affects the match outcome.

Over the duration of a tournament, movement patterns of the current group of players were essentially maintained. Only small differences were observed in activity at <5 m·s⁻¹ and moderate accelerations from the first to last tournament match. The preservation of work-rate between matches suggests that fatigue accumulated during a match is transient and the effect of any residual fatigue on subsequent performance is minimal. An additional explanation is that the between-match recovery strategies employed with this group of players including a combination of active and passive recovery, cryotherapy and cold water immersion [255], compression [111], nutritional intervention [24] and sleep [270] are effective in sustaining performance over a multi-day tournament.
Despite the relative stability of mean movement patterns between matches within a tournament, a high degree of variability in movement patterns was observed. Activity in rugby sevens is mediated by a multitude of factors including the dynamic demands of the game, the strength of the opposition, the capacity of players to regulate their performance and the unknown effects of environmental conditions, player fitness, team tactics and officiating style. Observations of large movement pattern variability are consistent with findings in elite soccer where variability in distance covered also increased with running velocity [77,117]. Further research is required to establish the longitudinal variability of rugby sevens movement patterns and the impact of internal (e.g., physiological, psychological) and external (e.g., environmental conditions, game styles) variables and their interaction. Future research incorporating GPS technology with a larger sample of teams may also identify positional differences in movement patterns and distinctions between successful and unsuccessful teams.

**Conclusion**

This study reported for the first time the differences in movement patterns within and between rugby sevens tournaments. The gross movement demands per min of rugby sevens are ~45% greater and relative high velocity running demands more than double those of rugby union. Although the total distance covered by players was similar between international and domestic matches, international matches were more intense owing to the greater distance covered at high velocities and higher number of accelerations and decelerations. Within matches, a small decrement in work-rate from the first to second half was observed. The relative distance covered by players at velocities >2 m·s\(^{-1}\) and the number of changes in velocity were reduced. Despite reductions in performance within individual matches, when recovery strategies are implemented there is little evidence of accumulated fatigue over a tournament. The findings of this preliminary study have implications for the selection and physical preparation of rugby sevens players.

**Practical Implications**

- Successful rugby sevens players are likely to require superior aerobic and anaerobic endurance capacity to rugby union players to tolerate the higher running demands.

- To optimise physical preparation of players, training should be specific to the competition tournament level (domestic or international).
• Small reductions in player work-rate can be expected between the first and second half of a rugby sevens match. Tactical player substitutions in the latter stages of a match can be used to maintain team work-rate.

• Player movement patterns should be reported per min of play and on an individual basis to account for differences in match time and between-player variability.

Acknowledgements

We gratefully acknowledge the cooperation of the players and the coaching and support staff in this project. This study was funded by the Australian Institute of Sport, Australian Rugby Union and the University of Canberra.
Chapter Seven - Physiological, Anthropometric and Performance Characteristics of Rugby Sevens Players


**Abstract**

Although the characteristics of 15-a-side rugby union players have been well defined, little information exists on rugby sevens players.

**Purpose:** We profiled the anthropometric, physiological and performance qualities of elite-level rugby sevens players, and quantified relationships between these characteristics.

**Methods:** Eighteen male international rugby sevens players undertook anthropometric (body mass, height, sum of seven skinfolds, lean mass index), acceleration and speed (40-m sprint), muscular power (vertical jump), repeated-sprint ability (6 × 30-m sprint) and endurance (Yo-Yo intermittent recovery test and treadmill $\dot{V}O_{2\text{max}}$) testing. Associations between measurements were assessed by correlation analysis.

**Results:** Rugby sevens players had anthropometric characteristics (body mass 89.7 ± 7.6 kg, height 1.83 ± 0.06 m, sum of skinfolds 52.2 ± 11.5 mm; mean ± SD) similar to backs in international 15-player rugby union. Acceleration and speed (40-m sprint 5.11 ± 0.15 s), muscular power (vertical jump 66 ± 7 cm), and endurance ($\dot{V}O_{2\text{max}}$ 53.8 ± 3.4 mL·kg$^{-1}$·min$^{-1}$) qualities were similar to, or better than, professional 15-a-side players. Coefficients of variation ranged from 2.5 to 22%. Relative $\dot{V}O_{2\text{max}}$ was largely correlated with Yo-Yo distance ($r = 0.60$, 0.21 to 0.82; 90% confidence interval) and moderately correlated with 40-m sprint time ($r = -0.46$, -0.75 to -0.02) and repeated-sprint ability ($r = -0.38$, -0.72 to 0.09).

**Conclusions:** International rugby sevens players require highly-developed speed, power and endurance to tolerate the demands of competition. The small between-athlete variability of characteristics in rugby sevens players highlights the need for relatively uniform physical and performance standards in contrast with 15-a-side players.
Key words: fitness testing, speed, endurance, training, team sports
Introduction

Rugby union is an international sport with demands broadly characterised by a high frequency of physical contacts and repeated intermittent bouts of high intensity activity [78]. To perform under these physiological demands, players need to develop endurance, power, speed and acceleration, and sport-specific skills. However, the specific demands of competition differ markedly between 15-player rugby union and rugby sevens. Rugby sevens is a format of rugby union that has increased in popularity in recent years and will be contested at the Olympic Games from 2016. The laws of rugby sevens, including the field dimensions, are substantially the same as 15-player rugby union with the major exceptions being the reduced number of players (seven per team) and shorter match duration (7-min halves). Differences in the physiological requirements of the two rugby formats suggest the characteristics of high-level players in each format may also differ.

Given the ~45% greater relative running volume and ~135% greater high velocity (>5 m·s⁻¹) running demands than 15-player rugby union [132], it is likely that international-level rugby sevens players will have high levels of endurance and different body fat and lean mass profiles compared with 15-a-side rugby union players. Although additional body fat may act as a protective buffer in contact situations, excess fat reduces a player’s power-to-weight ratio, ability to accelerate and increases energy expenditure [81]. As rugby sevens players are often selected based on their superior speed and endurance qualities, it is likely that a typical international-level player would have a relatively lower level of adipose tissue when compared with a 15-a-side player.

Studies of injury epidemiology [98], kinanthropometry and work-rate profiles [216], competition movement patterns [132,241], and immune markers [244] in rugby sevens indicate the basic anthropometric characteristics of players are substantially different from 15-a-side rugby players [96]. International rugby sevens backs are ~2 cm shorter and ~6 kg lighter than international 15-a-side backs, while forwards are ~1 cm shorter and ~13 kg lighter than their 15-a-side counterparts [98]. Although the physiological capacities of 15-a-side rugby union players have been reported [78], this information is not available on rugby sevens players. A comprehensive understanding of the anthropometric and fitness characteristics of top-level rugby sevens players is needed to guide talent identification and development programmes, individualise training prescription, and facilitate the transition of players to the more specialised sevens format. Furthermore, examining the association
between anthropometric and fitness attributes in rugby sevens players is needed for effective prescription of sport-specific strength and conditioning programmes. Quantifying relationships between laboratory- and field-based assessments will bridge the gap between cross-sectional player evaluations and on-field performance monitoring. The purpose of this study was to profile the physiological, anthropometric and performance characteristics of high-level rugby sevens players, and compare these results with previously published values for 15-a-side rugby union players. A secondary aim was to quantify the relationships between various anthropometric, physiological and performance test results.

**Methods**

**Experimental Approach**
A cross-sectional study design was used to assess the anthropometric, physiological and performance characteristics of members of a national men’s rugby sevens squad. Players were tested for anthropometry, acceleration and speed, lower-body muscular power, repeated-sprint ability and endurance in a seven day period during the international competition season. Tests were selected using recommendations for the assessment of rugby union players [81]. Players completed a standardised warm-up before starting the physical assessments. Sufficient recovery times were allowed between tests to ensure players gave a maximal effort and limit the influence of residual or cumulative fatigue on test results. Anthropometric assessments were performed prior to physiological testing to ensure players presented in a hydrated state. Players received verbal encouragement for each test to support a maximal effort. All equipment was calibrated before testing.

**Participants**
Eighteen male players (age 21.9 ± 2.0 years, mean ± SD) from a national rugby sevens squad provided written informed consent to participate in the study. Players were instructed to consume their normal pre-training diet and refrain from intense exercise at least 48 hours before the first day of testing. Only data collected on players free of injury and illness are reported. The study was approved by the University of Canberra Committee for Ethics in Human Research and Australian Institute of Sport Ethics Committee.

**Anthropometric Assessment**
Overnight fasted body mass, height and skinfold thickness were measured by an experienced, accredited anthropometrist using standard laboratory techniques [170]. The sum of biceps,
triceps, subscapular, suprailiac, abdomen, front thigh and medial calf skinfolds is reported. The typical error of measurement (TE) previously established through testing in our laboratory for sum of seven skinfolds is 1.3 mm and <1% for body mass and height. A lean mass index was calculated for each player as \(M \cdot S^{-0.14}\), where \(M\) is body mass (kg) and \(S\) is sum of skinfolds (mm) [82].

**Physiological and Performance Assessments**

**40-m Sprint**

To concurrently assess the players’ acceleration and maximum running velocity \(v_{\text{max}}\), a maximal sprint test over 40-m with intermediate split distances of 10-, 20- and 30-m was conducted indoors on a synthetic running track. Split and total times were recorded to the nearest 0.01 s using dual-beam electronic timing gates (Speedlight TT, Swift Performance Equipment, Lismore, Australia). Players started from a stationary standing (crouched) position 0.3 m behind the start timing gate. Players were given three trials and the fastest split times from the three trials were recorded for analysis. An estimate of \(v_{\text{max}}\) was obtained by subtracting the 30-m split time from the 40-m time and converting time to velocity (m·s\(^{-1}\)). Momentum (kg·m·s\(^{-1}\)) over the last 10-m of the sprint was calculated as the product of \(v_{\text{max}}\) and the player’s body mass (kg). The TE for the 40-m sprint is 0.04 s.

**Vertical Jump**

Lower-body muscular power was estimated using a jump height measuring device (Yardstick, Swift Performance Equipment, Lismore, Australia). A minimum of three double-foot stance counter-movement jumps with arm swing were performed until each player achieved their maximum jump height. Vertical jump height was calculated as the difference between maximum standing reach height and the highest point reached during the vertical jump. The TE for the vertical jump test is 1.5 cm.

**Yo-Yo Intermittent Recovery Level 1 Test**

The Yo-Yo intermittent recovery level 1 test (Yo-Yo IR1) was performed on an indoor synthetic running track under standardised conditions as a measure of endurance [20]. Briefly, the Yo-Yo IR1 consists of 2 × 20-m shuttle runs of increasing speed, interspersed with a 10-s activity recovery period. The Yo-Yo IR1 involves acceleration, deceleration and change of direction making it more specific to the work demands of rugby union than continuous running endurance tests. The total distance covered was recorded as the performance measure. The TE for the Yo-Yo IR1 is 90 m.
6 × 30-m Repeated-Sprint Ability Test

The 6 × 30-m repeated-sprint ability test is designed to evaluate a player’s speed-endurance qualities and ability to resist fatigue under time and distance demands similar to those experienced during a rugby union match. The test requires players to perform six maximal effort 30-m sprints starting on a 20-s cycle [203]. The repeated-sprint ability test was performed indoors on a synthetic track with players starting 1.0 m behind the electronic timing gates (Speedlight TT, Swift Performance Equipment, Lismore, Australia) for each sprint to reduce the likelihood of a false start. The cumulative time to complete the six sprints was recorded to the nearest 0.01 s for analysis. The TE for the repeated-sprint ability test is 0.7%.

\( \dot{V}O_{2\text{max}} \) Test

An incremental running test was conducted on a motorised treadmill under standardised laboratory conditions to determine players’ maximal oxygen uptake (\( \dot{V}O_{2\text{max}} \)) and running velocity at \( \dot{V}O_{2\text{max}} \) (\( \nu\dot{V}O_{2\text{max}} \)). The test started at 11 km·h\(^{-1}\) (0% gradient) increasing by 1 km·h\(^{-1}\)·min\(^{-1}\) to a speed of 14 km·h\(^{-1}\). Thereafter, the gradient increased by 1% each min until volitional exhaustion. Expired gas was analysed using a custom-built, automated Douglas bag gas analysis system. Velocity at \( \dot{V}O_{2\text{max}} \) was calculated by the linear regression of the submaximal speed-\( \dot{V}O_{2} \) relationship. Maximal oxygen uptake is reported in absolute units (L·min\(^{-1}\)) and relative to body mass (mL·kg\(^{-1}\)·min\(^{-1}\)). The TE for the \( \dot{V}O_{2\text{max}} \) test is 2.1%.

All players were familiar with the physiological assessment protocols except the \( \dot{V}O_{2\text{max}} \) and repeated-sprint ability tests, although players had been exposed to repeated-effort short interval sprints during previous fitness training sessions. Four players did not complete the repeated-sprint ability test, three players did not complete the \( \dot{V}O_{2\text{max}} \) test and Yo-Yo IR1, and two players did not complete the vertical jump and 40-m sprint due to injury or illness.

Statistical Analysis

Measures of centrality and spread are reported as mean ± SD. The between-athlete variability of measurements was calculated as the coefficient of variation expressed as a percent. The smallest worthwhile change for each assessment measure was calculated as 0.2 × between-athlete SD [139]. The smallest worthwhile change is defined as the smallest change in a test score likely to be relevant physiologically, or in performance terms, to the average player. Pearson product-moment correlation analyses were conducted to determine linear
relationships between independent measures. Magnitudes of correlation were classified using the following criteria: \( r = \pm 0 \) to 0.1 trivial, \( \pm 0.1 \) to 0.3 small, \( \pm 0.3 \) to 0.5 moderate, \( \pm 0.5 \) to 0.7 large, \( \pm 0.7 \) to 0.9 very large, and \( < -0.9 \) or \( > 0.9 \) nearly perfect. Precision of estimates are indicated by the 90% confidence interval, which defines the range representing the uncertainty in the true value of the unknown population mean. Relationships were reported as unclear when the confidence interval of the correlation coefficient crossed the threshold for both substantially positive (0.1) and negative (-0.1) values.

Results

**Anthropometric, Physiological and Performance Characteristics**

Anthropometric characteristics of the 12 backs and 6 forwards in the squad as well as the coefficient of variation and smallest worthwhile change for each measure are presented in Table 7.1. Between-athlete variability of sum of skinfolds (22%) was more than double that of other anthropometric measurements (3.3 to 8.4%). The performance and physiological assessment results of 16 players are presented in Table 7.2. The coefficient of variation for sprint, repeated-sprint and derived \( v_{\text{max}} \) measures was small (2.5 to 4.1%) and less than half that of the other field-based performance measures of vertical jump (10.9%) and Yo-Yo IR1 (11.9%). The low between-athlete variability in sprint times yielded a smallest worthwhile change of <0.04 s.

| Table 7.1. Anthropometric characteristics of international rugby sevens players (n = 18). |
|---------------------------------|--------|-----------|-------------|----------------|
|                                 | Body mass (kg) | Height (m) | Sum of seven skinfolds (mm) | Lean mass index (kg·mm\(^{0.14}\)) |
| Mean                           | 89.7   | 1.83      | 52.2         | 51.7           |
| SD                             | 7.6    | 0.06      | 11.5         | 4.3            |
| SWC                            | 1.5    | 0.01      | 2.3          | 0.9            |
| CV (%)                         | 8.4    | 3.3       | 22           | 8.4            |

SWC = smallest worthwhile change; CV = coefficient of variation.
Table 7.2. Performance and physiological characteristics of international rugby sevens players (n = 16).

<table>
<thead>
<tr>
<th>10-m sprint (s)</th>
<th>20-m sprint (s)</th>
<th>30-m sprint (s)</th>
<th>40-m sprint (s)</th>
<th>$v_{\text{max}}$ (m·s$^{-1}$)</th>
<th>Momentum (kg·m·s$^{-1}$)</th>
<th>Vertical jump (cm)</th>
<th>Repeated-sprint ability* (s)</th>
<th>Yo-Yo IR1 (m)†</th>
<th>$\dot{V}O_{2\text{max}}$ (L·min$^{-1}$)†</th>
<th>$\dot{V}O_{2\text{max}}$ (mL·kg$^{-1}$·min$^{-1}$)†</th>
<th>$v\dot{V}O_{2\text{max}}$ (m·s$^{-1}$)†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1.74</td>
<td>2.92</td>
<td>4.02</td>
<td>5.11</td>
<td>9.2</td>
<td>824</td>
<td>66.3</td>
<td>24.76</td>
<td>2256</td>
<td>4.81</td>
<td>53.8</td>
</tr>
<tr>
<td>SD</td>
<td>0.06</td>
<td>0.08</td>
<td>0.11</td>
<td>0.15</td>
<td>0.4</td>
<td>81</td>
<td>7.2</td>
<td>0.62</td>
<td>268</td>
<td>0.49</td>
<td>3.4</td>
</tr>
<tr>
<td>SWC</td>
<td>0.01</td>
<td>0.02</td>
<td>0.02</td>
<td>0.03</td>
<td>0.1</td>
<td>16</td>
<td>1.4</td>
<td>0.12</td>
<td>54</td>
<td>0.10</td>
<td>0.7</td>
</tr>
<tr>
<td>CV (%)</td>
<td>3.4</td>
<td>2.8</td>
<td>2.8</td>
<td>2.9</td>
<td>4.1</td>
<td>9.9</td>
<td>2.5</td>
<td>11.9</td>
<td>10.1</td>
<td>6.4</td>
<td>9.3</td>
</tr>
</tbody>
</table>

SWC = smallest worthwhile change; CV = coefficient of variation; $v_{\text{max}}$ = maximum velocity; $v\dot{V}O_{2\text{max}}$ = velocity at $\dot{V}O_{2\text{max}}$. *n = 14; †n = 15.
Associations between Anthropometric, Physiological and Performance Characteristics

Correlations between anthropometric, physiological and performance measures are presented in Table 7.3. Pair-wise correlations of 20- and 30-m sprint times with other variables closely mirrored the results of 40-m sprint time and are not shown. Several substantial relationships were observed between field- and laboratory-based performance and physiological measures (Table 7.4). Yo-Yo IR1 performance was largely correlated with relative \( \dot{V}O_2 \)max (Figure 7.1A), very largely correlated with \( v\dot{V}O_2 \)max (Figure 7.1B), moderately correlated with sum of skinfolds, and had unclear associations with other performance tests. Sprint time measured over 40-m was nearly perfectly related to repeated-sprint ability and had a moderate inverse association with absolute and relative \( \dot{V}O_2 \)max (Figure 7.1C). Relative \( \dot{V}O_2 \)max also had a moderate negative correlation with repeated-sprint time (Figure 7.1D).

Table 7.3. Associations between anthropometric, physiological and performance characteristics of international rugby sevens players (r, 90% confidence interval).

<table>
<thead>
<tr>
<th>Measure</th>
<th>Body mass (kg)</th>
<th>Height (m)</th>
<th>Sum of seven skinfolds (mm)</th>
<th>Lean mass index (kg·mm(^{-0.14}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-m sprint (s)</td>
<td>-0.28</td>
<td>-0.38</td>
<td>0.29</td>
<td>-0.38</td>
</tr>
<tr>
<td>40-m sprint (s)</td>
<td>-0.63 to 0.17</td>
<td>-0.69 to 0.06</td>
<td>-0.16 to 0.64</td>
<td>-0.70 to 0.05</td>
</tr>
<tr>
<td>( v_{\text{max}} ) (m·s(^{-1}))</td>
<td>-0.13</td>
<td>-0.27</td>
<td>0.45</td>
<td>-0.28</td>
</tr>
<tr>
<td>Momentum (kg·m·s(^{-1}))</td>
<td>-0.02</td>
<td>0.10</td>
<td>-0.40</td>
<td>0.10</td>
</tr>
<tr>
<td>Vertical jump (cm)</td>
<td>0.34</td>
<td>0.39</td>
<td>-0.10</td>
<td>0.39</td>
</tr>
<tr>
<td>Repeated-sprint ability (s)</td>
<td>-0.10</td>
<td>-0.21</td>
<td>0.51</td>
<td>-0.25</td>
</tr>
<tr>
<td>Yo-Yo IR1 (m)</td>
<td>-0.59 to 0.27</td>
<td>-0.64 to 0.20</td>
<td>-0.03 to 0.72</td>
<td>-0.67 to 0.14</td>
</tr>
<tr>
<td>( \dot{V}O_2 )max (L·min(^{-1}))</td>
<td>0.78</td>
<td>0.84</td>
<td>-0.26</td>
<td>0.83</td>
</tr>
<tr>
<td>( \dot{V}O_2 )max (mL·kg(^{-1})·min(^{-1}))</td>
<td>0.51 to 0.91</td>
<td>0.63 to 0.93</td>
<td>-0.63 to 0.21</td>
<td>0.62 to 0.93</td>
</tr>
<tr>
<td>( v\dot{V}O_2 )max (m·s(^{-1}))</td>
<td>-0.08</td>
<td>0.21</td>
<td>-0.45</td>
<td>0.06</td>
</tr>
<tr>
<td>( v\dot{V}O_2 )max (m·s(^{-1}))</td>
<td>-0.51 to 0.37</td>
<td>-0.26 to 0.60</td>
<td>-0.74 to -0.01</td>
<td>-0.39 to 0.49</td>
</tr>
</tbody>
</table>

\( v_{\text{max}} \) = maximum velocity; \( v\dot{V}O_2 \)max = velocity at \( \dot{V}O_2 \)max; \( n = 12 \) to 18.
Table 7.4. Associations between physiological and performance characteristics of international rugby sevens players (r, 90% confidence interval).

<table>
<thead>
<tr>
<th></th>
<th>10-m sprint (s)</th>
<th>40-m sprint (s)</th>
<th>v_{max} (m·s^{-1})</th>
<th>Momentum (kg·m·s^{-1})</th>
<th>Vertical jump (cm)</th>
<th>Repeated-sprint ability (s)</th>
<th>Yo-Yo IR1 (m)</th>
<th>V_{O2max} (L·min^{-1})</th>
<th>V_{O2max} (mL·kg^{-1}·min^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>v_{max} (m·s^{-1})</td>
<td>-0.59</td>
<td>-0.88</td>
<td>-0.81 to -0.22</td>
<td>-0.95 to -0.73</td>
<td>-0.50</td>
<td>-0.49</td>
<td>-0.77 to -0.10</td>
<td>-0.76 to -0.08</td>
<td>-0.58</td>
</tr>
<tr>
<td>Momentum (kg·m·s^{-1})</td>
<td>-0.50</td>
<td>-0.49</td>
<td>-0.88</td>
<td>-0.81 to -0.20</td>
<td>-0.77 to -0.10</td>
<td>-0.51</td>
<td>-0.09 to 0.67</td>
<td>0.06 to 0.75</td>
<td>-0.58</td>
</tr>
<tr>
<td>Vertical jump (cm)</td>
<td>-0.58</td>
<td>-0.51</td>
<td>0.35</td>
<td>0.47</td>
<td>-0.88</td>
<td>-0.45</td>
<td>-0.76 to 0.01</td>
<td>-0.76 to -0.01</td>
<td>-0.47</td>
</tr>
<tr>
<td>Repeated-sprint ability (s)</td>
<td>0.80</td>
<td>0.97</td>
<td>0.53 to 0.92</td>
<td>0.92 to 0.99</td>
<td>0.58 to 0.28</td>
<td>0.52 to 0.36</td>
<td>-0.12</td>
<td>-0.11</td>
<td>0.00</td>
</tr>
<tr>
<td>Yo-Yo IR1 (m)</td>
<td>-0.19</td>
<td>-0.09</td>
<td>0.15</td>
<td>-0.12</td>
<td>0.53 to 0.34</td>
<td>-0.53 to 0.35</td>
<td>-0.48</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>V_{O2max} (L·min^{-1})</td>
<td>-0.61</td>
<td>-0.45</td>
<td>0.25</td>
<td>0.37</td>
<td>-0.32</td>
<td>0.37</td>
<td>0.08</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>V_{O2max} (mL·kg^{-1}·min^{-1})</td>
<td>-0.83 to -0.23</td>
<td>-0.75 to -0.01</td>
<td>-0.22 to 0.62</td>
<td>0.63 to 0.93</td>
<td>-0.08 to 0.70</td>
<td>-0.68 to 0.16</td>
<td>-0.37 to 0.51</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>vV_{O2max} (m·s^{-1})</td>
<td>-0.50</td>
<td>-0.46</td>
<td>0.38</td>
<td>0.11</td>
<td>0.20</td>
<td>0.38</td>
<td>0.60</td>
<td>0.56</td>
<td>-</td>
</tr>
<tr>
<td>vV_{O2max} (mL·kg^{-1}·min^{-1})</td>
<td>-0.77 to -0.08</td>
<td>-0.75 to -0.02</td>
<td>-0.07 to 0.70</td>
<td>-0.35 to 0.53</td>
<td>-0.27 to 0.59</td>
<td>-0.72 to 0.09</td>
<td>0.21 to 0.82</td>
<td>0.15 to 0.80</td>
<td>-</td>
</tr>
</tbody>
</table>

v_{max} = maximum velocity; vV_{O2max} = velocity at V_{O2max}; n = 12 to 18.
Figure 7.1. Linear relationship between A) Yo-Yo intermittent recovery level 1 (Yo-Yo IR1) distance and relative $\dot{V}O_{2\text{max}}$ (n = 14), B) Yo-Yo IR1 distance and velocity at $\dot{V}O_{2\text{max}}$ (n = 14), C) relative $\dot{V}O_{2\text{max}}$ and 40-m sprint time (n = 14), and D) relative $\dot{V}O_{2\text{max}}$ and repeated-sprint ability (n = 12). Solid line represents regression line. Dashed line represents 90% confidence interval.

**Discussion**

This is the first study to concurrently profile the physiological, anthropometric and performance characteristics, and relationships between these qualities, in male rugby sevens players. To meet the physiological demands of both the 15-player and sevens formats of rugby, players require highly-developed speed, muscular power, and aerobic and anaerobic endurance [78]. The rugby sevens players in this study were 3 to 5 kg heavier and 4 cm taller than reports of sevens players in 1996 [216] and 2003 [244], but of a similar age, height and body mass to more recent reports of international players [98,132]. Our results confirm previous findings that, although younger, international rugby sevens players more closely resemble the height and body mass of international 15-a-side rugby union backs than forwards [98]. The players in this study were ~6 to 17 kg lighter and ~1 to 5 cm shorter than reports of professional 15-a-side rugby union players in studies that did not differentiate
between positional groups [4,8,63,67,110,111,232]. However, the sevens players were similar to the backs group in several studies (mean body mass range 85 to 93 kg, height 1.80 to 1.83 m) [62,66,82,83,227]. Similarly, rugby sevens players were substantially leaner than professional rugby union players (sum of skinfolds 15 to 61% lower) and exhibited a 1 to 14% lower lean mass index [82,232].

Variations in sprint starting protocols between studies may lead to slower times in the current study than previous reports [62,63]. Despite these differences, rugby sevens players in this study had similar sprint times over 10- and 20-m [63] and ~2% (0.07 to 0.12 s) faster times over 40-m than previous reports of elite rugby union players [78,111]. Rugby sevens players were ~6 to 8% faster than elite forwards up to 20-m, but only ~2% faster than elite backs for 20- and 30-m sprints [62]. Over 30- to 40-m, 15-a-side forwards reached a $v_{\text{max}}$ of 8.4 ± 0.4 m·s$^{-1}$ and backs, 9.2 ± 0.3 m·s$^{-1}$ [83], comparable to the 9.2 ± 0.4 m·s$^{-1}$ attained by players in this study. The peak velocity achieved by players during international rugby sevens tournaments (8.5 ± 1.1 m·s$^{-1}$) is in excess of 90% of the $v_{\text{max}}$ measured in the straight 40-m sprint [132]. Comparisons with published data suggest international-level rugby sevens players possess acceleration qualities similar to or exceeding those of elite rugby union players, and $v_{\text{max}}$ values comparable to professional 15-player rugby backs. A player’s momentum is another important consideration, especially in collisions, as greater size and speed is advantageous when attempting to effect or break a tackle [204]. To maximise performance, the training of rugby players should achieve the ideal balance between speed and body mass.

The absolute $\dot{V}O_{2\text{max}}$ of rugby sevens players was ~10% less than reported for international rugby union forwards [269], although similar to or greater than (~2 to 31%) international and professional players when reported relative to body mass [66,67,192,227,269]. The moderate aerobic power of rugby sevens players (~54 mL·kg$^{-1}$·min$^{-1}$) suggests it is only one of several requirements in the international player’s fitness profile. This notion is supported by the players’ performance in the team sport-specific Yo-Yo IR1 and repeated-sprint ability test. Yo-Yo IR1 performance was ~36% higher than results of professional rugby league players [10], but ~7% less than elite international soccer players [20]. The interpretation of repeated-sprint ability test results is typically protocol- and analysis-dependent. In agreement with previous observations, the cumulative time to complete six 30-m sprints was more closely related to single sprint times than aerobic capacity [203]. Repeated-sprint ability is
likely constrained by several physiological factors including aerobic capacity, anaerobic capacity, muscle excitability and neural drive, and muscle buffer capacity.

Despite their large correlation, the estimation of relative \( \dot{V}O_{2\text{max}} \) from field-based Yo-Yo IR1 performance is not recommended given the wide confidence interval of the relationship (Figure 7.1A). While both measures supposedly reflect underlying endurance qualities under maximal activation of the aerobic system, the Yo-Yo IR1 is an intermittent, team sport-specific test better representing players’ capacity to perform repeated high-intensity exercise [20]. The relatively low shared variance between Yo-Yo IR1 and relative \( \dot{V}O_{2\text{max}} \) (\( R^2 = 0.36 \)) suggests factors other than aerobic capacity are likely to affect performance in the field-based test. Studies of other sports demonstrate the Yo-Yo test is a more accurate predictor of on-field performance than \( \dot{V}O_{2\text{max}} \), and more sensitive in discriminating between athletes of different levels and evaluating training interventions [20]. The \( v\dot{V}O_{2\text{max}} \), incorporating both running economy and aerobic capacity, had a stronger relationship with Yo-Yo IR1 than \( \dot{V}O_{2\text{max}} \) with tighter confidence limits (Figure 7.1B). A player’s \( v\dot{V}O_{2\text{max}} \) may be a more useful indicator of running performance potential than \( \dot{V}O_{2\text{max}} \) alone.

High levels of aerobic and anaerobic endurance are required for competitive success in rugby sevens given the substantially higher running demands of rugby sevens tournaments when compared with 15-player rugby union [132,241]. Moreover, the tournament format of rugby sevens competitions necessitates rapid recovery of players to complete up to six matches over two days. To optimise physical preparation, players need to train to meet the work demands specific to their level of competition. There is an increase in the movement demands from domestic- to international-level rugby sevens tournaments (e.g., 27% greater distance covered per min at \( \geq 6 \) m·s\(^{-1} \) and 39% more high accelerations per min) [132]. The well-developed physiological qualities of international players may contribute to the higher intensity of play, and promote quicker recover within and between matches. Players with better-developed fitness qualities may also have a reduced risk of injury [99] and be less susceptible to fatigue-related errors in skill execution [102].

Correlations between anthropometric, performance and physiological measures emphasise the importance of physique and body composition in rugby sevens players. A higher sum of skinfold thickness was associated with poorer sprint times, \( v_{\text{max}} \), repeated-sprint ability, and relative \( \dot{V}O_{2\text{max}} \). For example, a 10 mm increase in skinfolds was associated with a 0.07 s
increase in 40-m sprint time; more than double the smallest worthwhile change. Surprisingly though, skinfolds were also positively related to Yo-Yo IR1 performance. Moderate correlations between \( \text{VO}_2\max \), acceleration, speed and repeated-sprint ability indicate international rugby sevens players have both highly-developed speed and aerobic endurance qualities. The need for lower-body power development and neuromuscular coordination is also demonstrated by the relationships between maximum vertical jump height, 10- and 40-m sprint time, \( v_{\text{max}} \), momentum, and repeated-sprint ability. The lower-body muscular power (vertical jump) of rugby sevens players was \( \sim 10\% \) greater than international-level players in 1994 [44], and similar to contemporary international-level players (66 ± 7 cm, mean ± SD, n = 29, unpublished data, Australian Rugby Union). Evidently, the physical preparation of rugby sevens players should limit levels of body fat which do not contribute to power development or endurance, and promote power production without negating endurance capacity.

Following the inclusion of rugby sevens into the Olympic Games and associated development of players and conditioning programmes, it is likely there will be greater specialisation of players between the two rugby formats. Historically, rugby sevens has been used as a development pathway for younger rugby players transitioning to international 15-a-side competition. Players in the current study were 5.7 years younger than 15-a-side rugby players during the International Rugby Board Rugby World Cup 2007 [96]. Younger players are likely to develop their absolute lean mass, strength and power qualities over a period of several years. Although measurement of additional strength qualities, such as maximum bench press, back squat and chin-up was not possible due to time constraints within the competitive season, these data would provide a more comprehensive description of the characteristics of elite rugby sevens players. Future studies should also address the effects of playing style, selection policy, and ethnicity on physical characteristics and movement patterns of sevens players in different nations, and in winning teams.

In rugby union there has traditionally been differentiation between the positional roles and physical requirements of backs and forwards [78]. Given the reduced number of players on the field in rugby sevens, there is a greater requirement for all players to develop a broad skill set and more similar physiological characteristics to meet the demands of play. The homogeneity of results within the current players, represented by the relatively small coefficients of variation, demonstrates the relative uniformity in characteristics between

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positions in rugby sevens. Irrespective of playing position, all rugby sevens players require speed, ball-handling skills, change of direction pace, adroit defensive skills, and strength and power to secure the ball in contact situations. Indeed, it is not uncommon for players competing as backs in 15-a-side rugby to play as forwards in rugby sevens.

The utility of fitness and anthropometric testing in rugby sevens players relates to the reliability (noise, expressed as a TE) of the test relative to the smallest worthwhile change (signal). The relatively low between-athlete variation in test results means the smallest worthwhile change likely to impact performance is also small for most tests. For example, the sum of skinfolds is a useful assessment for measuring changes in body fat levels because the signal exceeds the noise, while the vertical jump and 40-m sprint are acceptable because the signal is similar to the noise. Conversely, the Yo-Yo IR1 offers only marginal utility given the test reliability (90 m) is poorer than the smallest worthwhile change (54 m). Although tests such as the Yo-Yo IR1 are only marginally useful in detecting practically important changes in performance, this does not necessarily diminish their relative importance. Clearly, most coaches would regard sport-specific endurance as an important aspect of rugby performance. The reliability of laboratory- and field-based tests requires strict adherence to test protocols and calibration procedures, subject familiarisation, motivation and warm-up and, when appropriate, repeat trials. Collectively, the battery of assessments in this study provides an acceptable level of reliability to detect practically important changes in rugby sevens performance.

**Practical Applications**

Our findings provide an important first step toward the development of physical performance standards for players training to compete at the international level. Top-level rugby sevens players exhibit highly-developed characteristics across a range of fitness measures implying training programmes should develop all physical capacities. Endurance, speed, acceleration, repeated-sprint and power measures may be improved without compromising other qualities pertinent to performance. Based on the potential for competing demands, players training concurrently for both rugby union and rugby sevens should prioritise their training programme according to specific anthropometric and fitness requirements and timing of competitive seasons.

Although position-specific skill and physiological requirements must be considered when interpreting testing results, there is a need for players of all positions to achieve minimum
performance standards for competitive success at the international level. Assessing an individual player’s strengths and weaknesses facilitates the prescription of an individualised training programme [81]. Regular physiological and anthropometric assessments are recommended to monitor the physical development and progression of players. Simple field-based measures may be employed to assess training adaptations and prescribe velocity thresholds for performance monitoring in place of time-consuming and expensive laboratory-based tests. A structured testing regime conducted at various phases of the season (e.g., off-season, pre-season, mid-season) will assist in planning periodised training programmes and evaluating their effectiveness.

**Conclusion**

Elite male rugby sevens players have anthropometric characteristics similar to backs in international 15-player rugby union and acceleration and speed, lower-body muscular power, and relative maximal aerobic power attributes similar to, or exceeding, those of professional 15-a-side players. To meet the demands of competition, rugby sevens players require highly-developed speed, power and endurance qualities. The small between-athlete variability of characteristics in rugby sevens players highlights the need for relatively uniform physical and performance standards in contrast with 15-a-side players. Field-based testing provides a simple, inexpensive and effective method of evaluating fitness qualities in rugby sevens players.

**Acknowledgements**

We gratefully acknowledge the cooperation of the players and the coaching and support staff. Thank you to Laura Juliff and Stuart Graham of the Australian Institute of Sport for their assistance with data collection. No external financial assistance was obtained for this study.
Chapter Eight - Distribution of Fat, Non-osseous Lean and Bone Mineral Mass in International Rugby Union and Rugby Sevens Players


Abstract

Differences in the body composition of international rugby union and rugby sevens players, and between players of different positions are poorly understood. The purpose of this study was to examine differences in the quantity and regional distribution of fat, non-osseous lean and bone mineral mass between playing units in rugby union and rugby sevens. Male rugby union (n = 21 forwards, 17 backs) and rugby sevens (n = 11 forwards, 16 backs) players from the Australian national squads were measured using dual-energy X-ray absorptiometry. The digital image of each player was partitioned into anatomical regions including the arms, legs, trunk, and android and gynoid regions. Compared with backs, forwards in each squad were heavier and exhibited higher absolute regional fat (union 43 to 67%; ±~17%, range of % differences; ±~95% confidence limits (CL); sevens 20 to 26%; ±~29%), non-osseous lean (union 14 to 22%; ±~5.8%; sevens 6.9 to 8.4%; ±~6.6%) and bone mineral (union 12 to 26%; ±~7.2%; sevens 5.0 to 11%; ±~7.2%) mass. When tissue mass was expressed relative to regional mass, differences between rugby sevens forwards and backs were mostly unclear. Rugby union forwards had higher relative fat mass (1.7 to 4.7%; ±~1.9%, range of differences; ±~95% CL) and lower relative non-osseous lean mass (-4.2 to -1.8%; ±~1.8%) than backs in all body regions. Competing in rugby union or rugby sevens characterised the distribution of fat and non-osseous lean mass to a greater extent than a player’s positional group, whereas the distribution of bone mineral mass was associated more with a player’s position. Differences in the quantity and distribution of tissues appear to be related to positional roles and specific demands of competition in rugby union and rugby sevens.

Key words: anthropometry, physique, body composition, adiposity, dual-energy X-ray absorptiometry
Chapter 8 – Distribution of Fat, Non-osseous Lean and Bone Mineral Mass in International Rugby Union and Rugby Sevens Players

Introduction

Physique traits of players are important factors associated with success in international rugby union. In the Rugby World Cup, the height and mass of players increased progressively between 1987 and 2007, with higher ranking teams having taller backs and heavier forwards [228]. A greater body mass is advantageous during physical contests for the ball. However, when additional mass is carried as fat, a player’s power-to-weight ratio, acceleration and metabolic efficiency may be compromised [277]. Higher relative fat mass is also associated with a greater reliance on carbohydrate metabolism [154] and may impair thermoregulation [230]. Quantifying a player’s body composition therefore provides valuable information for dietary and training prescription.

Rugby sevens is a shortened format of rugby union that will debut at the Olympic Games in 2016. Rugby sevens competitions are contested in a tournament format where matches are played over 7-min halves (10-min halves in tournament finals) with seven players on the field for each team. The relationship between kinanthropometric measures and performance in rugby sevens is unclear [216]. Given the higher relative movement demands and reduced emphasis on physical contact of rugby sevens compared with rugby union [132], it is likely the body composition of international-level players in each format also differ [133]. Understanding the physique characteristics of rugby union and rugby sevens players could assist in directing players into the rugby format and positional group to which they are best physically suited. This information could also be used to increase the specificity of physical preparation and dietary programmes.

Although body composition is typically described at a whole-body level, dual-energy X-ray absorptiometry (DXA) enables valid and reliable measurement of regional body composition [184]. Limited information exists regarding the relationship between regional distribution of tissue and sporting performance. Faster sprinters have lower relative body fat and greater muscle thickness in the upper thigh than their slower peers [160]. Deposition of mass more proximal to the joint may enhance biomechanical efficiency, offering a performance advantage [221]. Preliminary research has identified differences in the quantity and distribution of fat, non-osseous lean and bone mineral mass between rugby union backs and forwards [27]. These differences appear to be related to variations in competition requirements and playing roles of positional groups. However, to date no published data exist on players competing at the highest level of international rugby union or rugby sevens.
competition. The purpose of this study was to quantify and compare the regional distribution of fat, non-osseous lean and bone mineral mass measured by DXA between positional groups in international-level rugby union and rugby sevens.

**Methods**

**Experimental Approach**
A cross-sectional design was employed to compare the regional quantity and distribution of fat, non-osseous lean and bone mineral mass. Rugby union players underwent a DXA scan 20 ± 3 days (mean ± SD), and rugby sevens players 43 ± 16 days, prior to the commencement of their respective international competitions.

**Participants**
Thirty-eight rugby union and 27 rugby sevens players in the national men’s squads representing Australia in international competition (world ranking at the time of the study: rugby union, 2nd; rugby sevens, 6th) provided informed consent to participate in the study. Players in each squad were assigned to groups based on their playing position as either forwards (union n = 21; sevens n = 11) or backs (union n = 17; sevens n = 16). The study procedures had institutional ethics committee approval and conformed to the standards of the International Journal of Sports Medicine [127].

**Standardised DXA Measurement and Analysis**
The body composition of players was measured using a whole-body DXA scan. Players were scanned in the morning following an overnight fast and had not undertaken any exercise on the morning of the scan. Players were scanned with standardised positioning wearing light clothing and with all jewellery and metal objects removed [184]. Given geographical constraints and player availability it was not possible to use the same DXA scanner for all players. Rugby union players were measured using a Hologic Discovery A fan-beam scanner (Hologic Inc., Bedford, MA) and rugby sevens players with a Lunar Prodigy narrow-angle fan-beam scanner (GE Healthcare, Madison, WI). Scanners were calibrated according to manufacturers’ guidelines. Quality assurance and quality control procedures were conducted daily before measurement using phantom blocks of known density. One experienced operator conducted and analysed all scans for rugby union players, and another experienced operator conducted and analysed all scans for the rugby sevens squad. Players too large to fit within the scan area of the machine were measured using multiple scans [185]. The typical error of
measurement expressed as a coefficient of variation (%) for whole-body and regional DXA measurements in males using the Lunar Prodigy scanner is 1.9 to 3.7% for fat, 0.4 to 1.5% for non-osseous lean and 0.5 to 2.2% for bone mineral mass [184]. The Hologic scanner demonstrates coefficients of variation ranging from 0.2 to 3.5% [224].

Scans of rugby union players were analysed using Apex software (version 3.3, Hologic Inc., Bedford, MA) and rugby sevens players with enCORE software (version 13.6, GE Healthcare, Madison, WI). The digital image of the player was partitioned into anatomical regions including the head, arms, legs, trunk, android and gynoid regions (Figure 8.1). Horizontal lines were placed directly inferior to the mandible to mark the head and at the level of the iliac crests. Lines running through the glenohumeral joints, isolating the arms from the trunk, joined the superior and inferior horizontal lines. Oblique lines running from the horizontal line at the level of the iliac crest through the femoral necks separated the trunk and legs. Lines placed lateral to the legs separated the arms and legs, and a line placed medial to the legs separated left and right leg. The android region was defined by an inferior border at the iliac crest line, a superior border 20% of the distance between iliac crest and mandible lines, and lateral borders at the lines separating the trunk and arms. The gynoid region was defined by a superior border below the iliac crest line at a level 1.5 times the vertical length of the android region. The vertical length of the gynoid region was twice the vertical length of the android region with lateral borders at the lines lateral to each leg.

Figure 8.1. Example DXA scan image partitioned into regions of interest for analysis.
Chapter 8 – Distribution of Fat, Non-osseous Lean and Bone Mineral Mass in International Rugby Union and Rugby Sevens Players

Statistical Analysis

Given differences in the partitioning of tissue measured using DXA scanners of different models and lack of population-specific cross-calibration equations for each tissue and region of interest [231], total mass along with absolute and relative quantities of each tissue mass in the arms, legs, trunk, android and gynoid segments were analysed separately for the rugby union and rugby sevens squads. In the android and gynoid regions, only fat mass was analysed. In the context of this study, “fat” refers to extractable lipids such as triglycerides and fatty acids, primarily found in adipose tissue but also present in skeletal muscle, organs and bone marrow. Conversely, “adipose tissue” refers to masses under the skin (subcutaneous) and surrounding muscles and organs (visceral) separable by dissection, composed chiefly of lipids, but also water, protein and minerals [46]. The proportion of mass in each region relative to DXA-derived whole-body mass was also analysed for each positional group within each squad. Descriptive data are presented as mean ± SD. A ratio of each tissue mass in the arms, legs and trunk to the corresponding whole-body tissue mass was calculated to indicate the regional distribution of tissue independent of the absolute quantity of tissue. Principal components analyses were conducted on the ratio values to identify the distribution of each tissue for all players. Components with eigenvalues >1.0 were considered meaningful. Component scores were compared between backs and forwards regardless of their squad, between rugby sevens and rugby union players and between positional groups within and between squads.

Magnitude-based inferences on differences between positional groups and squads were made by standardising differences using the between-player SD. Positional group differences in whole-body mass and the absolute mass of each tissue in each region were assessed via log-transformed data to reduce the non-uniformity of error, and back-transformed to obtain differences in means as percents. Magnitudes of standardised differences in means were assessed as 0 to 0.2 being trivial, 0.2 to 0.6 small, 0.6 to 1.2 moderate, 1.2 to 2.0 large and >2.0 very large. To reduce the chance of errors regarding inferences, precision of estimates were indicated with 95% confidence limits. Differences were reported as unclear when the confidence interval of the standardised difference crossed the threshold for both substantially positive (0.2) and negative (-0.2) values.
Chapter 8 – Distribution of Fat, Non-osseous Lean and Bone Mineral Mass in International Rugby Union and Rugby Sevens Players

Results

Age and Body Mass
Rugby union forwards (25.3 ± 3.4 years) and backs (24.5 ± 1.9 years) were older than their rugby sevens counterparts (forwards 22.4 ± 2.3 years; backs 21.5 ± 2.0 years), but there were no clear differences in the ages of backs and forwards within the same squad. Backs were lighter than forwards in each squad. There was a large difference in whole-body mass between rugby sevens forwards (95.0 ± 5.1 kg) and backs (87.4 ± 7.3 kg), whereas the difference between rugby sevens forwards and rugby union backs (92.3 ± 6.8 kg) was unclear. Rugby union backs were moderately heavier than rugby sevens backs, while rugby union forwards (111.7 ± 7.9 kg) exhibited very large differences in body mass compared with all other groups.

Absolute Regional Tissue Mass
Forwards in rugby union had large to very large positive differences in every tissue mass across all regions compared with backs, with the exception of only moderately greater bone mass in the left leg (Table 8.1). Forwards in rugby sevens had more absolute fat mass in the gynoid region, but an unclear difference in the android region compared with backs. Rugby sevens forwards also had moderately greater fat, non-osseous lean and bone mineral mass than backs in the arms, legs and trunk (Table 8.1).
Table 8.1. Differences in absolute regional tissue mass between forwards and backs in rugby union and rugby sevens.

<table>
<thead>
<tr>
<th>Region</th>
<th>Tissue Mass (g)</th>
<th>Rugby union</th>
<th>Rugby sevens</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Forwards (n = 21)</td>
<td>Backs (n = 17)</td>
<td>Forwards (n = 11)</td>
</tr>
<tr>
<td>Android</td>
<td>Fat</td>
<td>1165 ± 392</td>
<td>723 ± 244</td>
</tr>
<tr>
<td>Gynoid</td>
<td>Fat</td>
<td>3400 ± 709</td>
<td>2116 ± 568</td>
</tr>
<tr>
<td>Left arm</td>
<td>Fat</td>
<td>960 ± 216</td>
<td>645 ± 165</td>
</tr>
<tr>
<td></td>
<td>Lean</td>
<td>6064 ± 541</td>
<td>5020 ± 464</td>
</tr>
<tr>
<td></td>
<td>Bone</td>
<td>328 ± 29</td>
<td>265 ± 26</td>
</tr>
<tr>
<td>Right arm</td>
<td>Fat</td>
<td>976 ± 224</td>
<td>682 ± 179</td>
</tr>
<tr>
<td></td>
<td>Lean</td>
<td>6409 ± 632</td>
<td>5252 ± 428</td>
</tr>
<tr>
<td></td>
<td>Bone</td>
<td>354 ± 31</td>
<td>282 ± 28</td>
</tr>
<tr>
<td>Left leg</td>
<td>Fat</td>
<td>3373 ± 721</td>
<td>2040 ± 472</td>
</tr>
<tr>
<td></td>
<td>Lean</td>
<td>15889 ± 1483</td>
<td>13821 ± 979</td>
</tr>
<tr>
<td></td>
<td>Bone</td>
<td>814 ± 86</td>
<td>724 ± 68</td>
</tr>
<tr>
<td>Right leg</td>
<td>Fat</td>
<td>3418 ± 714</td>
<td>2114 ± 530</td>
</tr>
<tr>
<td></td>
<td>Lean</td>
<td>16082 ± 1530</td>
<td>14086 ± 1038</td>
</tr>
<tr>
<td></td>
<td>Bone</td>
<td>813 ± 96</td>
<td>710 ± 63</td>
</tr>
<tr>
<td>Trunk</td>
<td>Fat</td>
<td>7056 ± 2312</td>
<td>4202 ± 1390</td>
</tr>
<tr>
<td></td>
<td>Lean</td>
<td>42751 ± 2733</td>
<td>36912 ± 2902</td>
</tr>
<tr>
<td></td>
<td>Bone</td>
<td>1391 ± 203</td>
<td>1149 ± 134</td>
</tr>
</tbody>
</table>

Lean = non-osseous lean tissue; + indicates a substantially larger tissue mass in forwards compared with backs.
Relative Regional Tissue Mass

Relative to the total mass in each region, non-osseous lean tissue proportionately comprised the greatest mass in both rugby sevens and rugby union players, while bone comprised the least (Table 8.2). In rugby union players, forwards had moderately lower relative bone mineral mass in the legs than backs (Table 8.2). Compared with rugby union backs, forwards had greater relative fat mass in all regions, offset by lower relative non-osseous lean mass in the arms, legs and trunk. With the exception of lower right leg bone mineral mass in forwards compared with backs, there were no clear differences in relative tissue mass between positional groups in rugby sevens when tissue mass was analysed as a proportion of total regional mass (Table 8.2).
Table 8.2. Differences in relative regional tissue mass between forwards and backs in rugby union and rugby sevens.

<table>
<thead>
<tr>
<th>Region</th>
<th>Tissue Mass (%)</th>
<th>Rugby union</th>
<th>Rugby sevens</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Forwards (n = 21)</td>
<td>Backs (n = 17)</td>
<td>Forwards (n = 11)</td>
</tr>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Difference; ±95% CL</td>
<td>Qualitative outcome</td>
</tr>
<tr>
<td>Android</td>
<td>Fat</td>
<td>16.0 ± 4.0</td>
<td>12.3 ± 2.5</td>
</tr>
<tr>
<td></td>
<td>Lean</td>
<td>82.4 ± 3.1</td>
<td>84.7 ± 1.9</td>
</tr>
<tr>
<td></td>
<td>Bone</td>
<td>4.5 ± 0.3</td>
<td>4.5 ± 0.4</td>
</tr>
<tr>
<td>Left arm</td>
<td>Fat</td>
<td>15.1 ± 3.2</td>
<td>10.8 ± 2.0</td>
</tr>
<tr>
<td></td>
<td>Lean</td>
<td>82.7 ± 3.4</td>
<td>84.5 ± 2.2</td>
</tr>
<tr>
<td></td>
<td>Bone</td>
<td>4.6 ± 0.4</td>
<td>4.5 ± 0.3</td>
</tr>
<tr>
<td>Right arm</td>
<td>Fat</td>
<td>12.7 ± 3.2</td>
<td>10.9 ± 2.2</td>
</tr>
<tr>
<td></td>
<td>Lean</td>
<td>82.7 ± 3.4</td>
<td>84.5 ± 2.2</td>
</tr>
<tr>
<td></td>
<td>Bone</td>
<td>4.6 ± 0.4</td>
<td>4.5 ± 0.3</td>
</tr>
<tr>
<td>Left leg</td>
<td>Fat</td>
<td>16.7 ± 3.0</td>
<td>12.3 ± 2.3</td>
</tr>
<tr>
<td></td>
<td>Lean</td>
<td>79.2 ± 2.9</td>
<td>83.4 ± 2.1</td>
</tr>
<tr>
<td></td>
<td>Bone</td>
<td>4.1 ± 0.4</td>
<td>4.4 ± 0.3</td>
</tr>
<tr>
<td>Right leg</td>
<td>Fat</td>
<td>16.8 ± 3.0</td>
<td>12.5 ± 2.5</td>
</tr>
<tr>
<td></td>
<td>Lean</td>
<td>79.2 ± 3.0</td>
<td>83.3 ± 2.4</td>
</tr>
<tr>
<td></td>
<td>Bone</td>
<td>4.0 ± 0.3</td>
<td>4.2 ± 0.3</td>
</tr>
<tr>
<td>Trunk</td>
<td>Fat</td>
<td>13.6 ± 3.7</td>
<td>9.8 ± 2.4</td>
</tr>
<tr>
<td></td>
<td>Lean</td>
<td>83.7 ± 3.6</td>
<td>87.4 ± 2.2</td>
</tr>
<tr>
<td></td>
<td>Bone</td>
<td>2.7 ± 0.3</td>
<td>2.7 ± 0.3</td>
</tr>
</tbody>
</table>

Lean = non-osseous lean tissue; + or – indicates a substantially larger or smaller proportional tissue mass in forwards compared with backs, respectively.
Distribution of Mass

There were no clear differences between positions in rugby sevens players when regional mass was expressed relative to DXA-derived whole-body mass (Figure 8.2A). Rugby union forwards had higher proportional mass in the arms compared with backs (small standardised differences), but unclear differences in other regions (Figure 8.2B). Players in both squads carried the largest proportion of their mass in the trunk, followed by the legs and arms.

![Distribution of Mass](image.png)

*Figure 8.2. Regional mass of rugby sevens (A) and rugby union (B) backs and forwards as a proportion of DXA-derived whole-body mass (mean + SD). *Greater relative regional mass in forwards than backs (small standardised difference).

Distribution of Tissue

Two principal components were considered to be meaningful for each tissue distribution, collectively explaining 72 to 96% of the variance in distribution (Table 8.3). The first principal component of fat accounted for 74% of the variance in regional mass distribution in
all players. The first component of fat distribution characterised a trunk-extremity contrast, representing a continuum from total fat deposition at the trunk to total deposition at the limbs, through a high negative loading of the trunk (-0.98) and high positive loading of the arms (left 0.81, right 0.83) and legs (left 0.82, right 0.84) (Table 8.3). The second fat component accounted for 22% of the distribution variance and identified a lower limb-upper limb contrast. The first non-osseous lean tissue component characterised a trunk-upper limb contrast, while the second component demonstrated an upper body-lower body contrast. The first bone mineral mass component contrasted the trunk and legs with the arms, while the second component characterised a trunk-extremity contrast.
Table 8.3. Principal components of combined relative regional fat, non-osseous lean and bone mineral mass.

<table>
<thead>
<tr>
<th></th>
<th>Component 1</th>
<th>Component 2</th>
<th>Component 1</th>
<th>Component 2</th>
<th>Component 1</th>
<th>Component 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat mass</td>
<td>0.81</td>
<td>0.54</td>
<td>0.92</td>
<td>-0.32</td>
<td>0.78</td>
<td>0.38</td>
</tr>
<tr>
<td>Right arm</td>
<td>0.83</td>
<td>0.52</td>
<td>0.93</td>
<td>-0.24</td>
<td>0.86</td>
<td>0.21</td>
</tr>
<tr>
<td>Left leg</td>
<td>0.82</td>
<td>-0.53</td>
<td>0.12</td>
<td>0.93</td>
<td>-0.35</td>
<td>0.86</td>
</tr>
<tr>
<td>Right leg</td>
<td>0.84</td>
<td>-0.51</td>
<td>0.11</td>
<td>0.91</td>
<td>-0.44</td>
<td>0.80</td>
</tr>
<tr>
<td>Trunk</td>
<td>-0.98</td>
<td>0.01</td>
<td>-0.92</td>
<td>-0.33</td>
<td>-0.46</td>
<td>-0.39</td>
</tr>
<tr>
<td>Eigenvalue</td>
<td>3.69</td>
<td>1.09</td>
<td>2.58</td>
<td>1.97</td>
<td>1.87</td>
<td>1.72</td>
</tr>
<tr>
<td>Variance (%)</td>
<td>74</td>
<td>22</td>
<td>52</td>
<td>39</td>
<td>37</td>
<td>34</td>
</tr>
<tr>
<td>Distribution</td>
<td>Trunk-extremity</td>
<td>Lower limb-upper limb</td>
<td>Trunk-upper limb</td>
<td>Lower body-upper body</td>
<td>Trunk/lower limb-upper limb</td>
<td>Trunk-extremity</td>
</tr>
</tbody>
</table>
There was substantial variation in principal component scores by squad and positional group for fat (Figure 8.3A), non-osseous lean (Figure 8.3B) and bone mineral (Figure 8.3C) mass. Substantial differences between rugby union and rugby sevens players were observed for both fat components (first component very large standardised difference; second component small difference), both non-osseous lean components (first component very large difference; second component small difference) and the first bone mineral component (moderate difference). In other words, compared with rugby union players, rugby sevens players had greater fat deposition in the trunk than limbs and in the lower rather than upper limbs, stored greater lean soft-tissue mass in the arms than trunk, and stored more bone mineral mass in their trunk and legs than arms.
Chapter 8 – Distribution of Fat, Non-osseous Lean and Bone Mineral Mass in International Rugby Union and Rugby Sevens Players

Figure 8.3. Principal component scores of rugby union and rugby sevens backs and forwards for fat (A), non-osseous lean (B) and bone mineral (C) mass distribution. Mean ± 95% confidence interval is shown for each group.

The combined forwards were moderately higher than backs in the first bone mineral component indicating that, relative to backs, forwards deposited more bone in the arms than trunk and legs. Forwards were also lower than backs by a small magnitude in the second
components of fat and bone mineral mass, indicating that, relative to backs, forwards deposited more fat in the legs than arms and more bone in the trunk than limbs. Positional group differences were unclear for non-osseous lean mass distribution.

Compared with all other players, rugby union backs carried relatively more fat in the arms than legs (Figure 8.3A; moderate differences with other groups) and greater lean soft tissue in the trunk than arms (Figure 8.3B; small to very large differences). In contrast, rugby union forwards deposited relatively greater bone mineral mass in the arms than trunk and legs compared with all other players (Figure 8.3C; moderate to large differences). Rugby union forwards also had more non-osseous lean mass in the trunk than arms compared with rugby sevens players (large differences), but less than rugby union backs (small difference) (Figure 8.3B).

Discussion
Knowledge of the body size and composition characteristics of elite-level rugby players is important for monitoring adaptations to training and diet, as well as informing the selection of players in apposite positions and/or rugby formats. This is the first study to compare the regional composition and distribution of mass between backs and forwards in international-level rugby union and rugby sevens. The findings offer insight into the quantity and distribution of tissue mass of internationally-competitive players in regard to playing position and game format. Given the international standard of the players in this study, the results provide reference values useful for talent identification and transfer purposes. Forwards are characterised by a higher whole-body mass, as well as greater fat, lean and bone mass compared with backs, although to a lesser extent in rugby sevens. In addition, the anatomical distribution of tissue varies between positional groups and rugby formats.

Positional Group Differences in Tissue Mass
Forwards have a greater body mass than backs in both rugby union and rugby sevens, which is not surprising given differences in positional roles during competition. The primary objective of forwards is to contest possession in set-piece plays as well as rucks and mauls, while backs use possession to gain territory and score points. Whole-body mass differences between positions derive from forwards having more adipose, non-osseous lean and bone tissue. Although the positional group differences are consistent between rugby union and rugby sevens, the magnitude of difference between forwards and backs was greater in union players. Smaller positional group differences in rugby sevens players in absolute tissue
masses are consistent with previous findings of relatively uniform anthropometric, physiological and performance characteristics [133].

Linear momentum is the product of mass and velocity. When other attributes remain constant, a higher body mass produces a higher momentum regardless of the type of tissue of the additional mass. Greater momentum is beneficial during contests for the ball and when effecting or breaking a tackle. However, applying Newton’s second law of motion \( F = m \cdot a \) suggests that additional mass \( m \) in the form of non-functional adipose tissue will be detrimental to a player’s ability to accelerate \( a \) without a corresponding increase in the muscle force \( F \) applied. Despite this, there has been a progressive increase in the body mass of rugby players of all positions in recent decades as players attempt to gain a physical advantage over opponents [193,205,228]. Increasing whole-body mass through excess energy intake alone typically results in greater proportional gains in fat than fat-free mass [162], as optimising muscle hypertrophy is a multifactorial process [225]. The comparative complexity of increasing lean rather than fat mass may partially explain the higher absolute and relative fat mass in rugby union forwards compared with backs in the same squad.

Forwards in rugby union sprint less [13,84,220] and have more contacts [256] than backs during competition. It is likely an increase in fat mass has less of an effect on the movement profile of a forward compared with a back. However, given the higher requirements for speed and endurance [132] and smaller differences in the activity profiles of forwards and backs in rugby sevens competition [134], the greater homogeneity of regional tissue mass proportions observed in this study was not unexpected. Although positional differences in rugby sevens players were unclear when tissue mass was expressed as a proportion of total regional mass, differences between backs and forwards followed the trends observed in the rugby union players. In other words, forwards tended to have slightly greater relative fat mass, lower relative non-osseous lean mass and similar or lower relative bone mineral mass than backs across all regions. The greater fat mass in forwards may attenuate the high forces transferred during contact [26]. Despite the purported role of fat mass as a physical buffer, there is little evidence the quantity or distribution of adipose tissue offers such protection [201]. Longitudinal research utilising large numbers of players of different positions is needed to elucidate relationships between physique characteristics and risk of injury.

A compromise between a player’s size and mobility may be necessary for fully meeting the position-specific demands of training and competition. The ideal physique characteristics
most likely to positively influence locomotion and movement patterns typical of rugby competition, including the translation of force during contact, require further investigation. Although the technical skill components of rugby-specific tasks must be acknowledged, additional research is needed to examine associations between the quantity and distribution of tissue in rugby players and functional measures, such as power, agility, running speed and scrumming force.

**Distribution of Mass**

Quantifying the regional distribution of mass may be useful in highlighting priorities for physical player development. The combined mass of the legs expressed as a proportion of whole-body DXA-derived mass of players in this study (~35 to 36%) was similar to lower-level rugby union players and their recreationally-active controls matched for body mass index (~35%) [27], but less than U.S. Army Rangers candidates (~39%) [190]. Trunk mass comprised ~45% of whole-body DXA mass, which was greater than U.S. Army Rangers candidates (~43%) [190], but less than lower-level rugby union players and controls (~48%) [27]. Combined arm mass accounted for ~13 to 14% of DXA-derived mass, higher than both U.S. Army Rangers candidates (~12%) [190] and lower-level rugby union players (~12%) [27]. The arms are important for many rugby-specific skills. With the exception of passing, many of these skills relate to contact situations, such as fending, lifting, tackling, grappling and turning opposition players, and binding during scrums, rucks and mauls. The relatively high proportional arm mass in international-level players indicates the importance of supporting these skills by increasing arm mass, primarily through the development of lean tissue. Rugby union forwards had a greater proportion of total mass in the arms compared with rugby union backs, again highlighting the importance of mass in the upper limbs for contact-related skills.

The lower body of rugby players contributes to performance through power produced during skills such as rucking, mauling, scrumming, jumping during line-outs, and running. The trunk is also an important constituent of a player’s physique, creating a stable framework for generating and transferring force during contact [179]. It is apparent that a strong trunk and legs are essential constituents in optimising a player’s performance. The trunk contains a high proportion of non-osseous lean mass from organs, whereas the soft-tissue lean mass of limbs is composed almost entirely of skeletal muscle tissue. Although non-osseous lean tissue is not a substitute for muscle tissue, a higher proportional lean mass is likely to improve a player’s ability to produce force and power. Given variations in competition demands, the optimal
total mass and ratio of regional lean and fat mass differ substantially between positions and between rugby union and rugby sevens. Specialised training and dietary interventions may be necessary for optimising a player’s physique specific to their position and game format.

**Distribution of Fat**

The first principal component of fat distribution characterised a trunk-extremity contrast, consistent with previous observations in athletes and non-athletes [23,169,183]. This pattern of fat deposition is consistent across ethnic groups and reflects a masculine characteristic associated with sex-hormone levels [23]. Explanations for substantial differences in fat distribution between rugby union and rugby sevens players regardless of position, and a small difference between forwards and backs in lower limb-upper limb fat distribution regardless of squad, require further study. Although sport participation and specialised training for competition have a larger effect on absolute body-fat levels than fat distribution [169], other lifestyle and biological factors may influence differences in fat deposition. For example, testosterone is an important regulator of the distribution of central and peripheral adipose tissue in men [34]. Anatomical fat distribution is also influenced by ethnicity [23,169]. Eight players in each squad (backs and forwards) were of Polynesian, Melanesian or Aboriginal Australian ethnicity. Although the distribution of tissue mass appears to be largely biological with relatively little influence of competing in sport, the interaction of genetic and environmental factors influencing tissue distribution requires further examination.

**Distribution of Non-osseous Lean Mass**

Magnitudes of difference between the squads in non-osseous lean mass distribution were concordant with differences in fat distribution. Rugby union backs and forwards had trunk-upper limb distribution contrasts that were not only distinct from rugby sevens players, but also each other. However, differences in distribution between backs and forwards regardless of the rugby format they played were unclear. A previous study of non-osseous lean tissue distribution in lower-level rugby union players concluded that the arms and legs contribute equally to playing performance based on similar principal component loadings at these sites [27]. Our investigation of international-level players produced different results, showing a primary trunk-arm contrast explaining 52% of variance in distribution. The legs had a high positive loading in the second non-osseous lean mass component, but as with fat and bone mass, the second component scores were closer to zero than the first component in all groups, indicating less contrast between the lower and upper body. The observed distribution patterns highlight the importance of lean mass development in the upper body for top-level players.
**Distribution of Bone Mineral Mass**

The two components of bone mineral mass explained a similar proportion of the variance in distribution. Differences between squads and between positional groups in the first component were moderate. However, a small difference was present between backs and forwards in the second component regardless of their squad, while the difference between rugby sevens and rugby union was unclear. The distribution of bone mineral mass was distinct for rugby union forwards by their propensity to store a greater proportion of mass in the arms than all other groups. Enhanced appendicular skeletal mass accretion in the arms of rugby union forwards is likely the result of adaptation to bone deformations due to vibration and strain induced by muscle contractions and a high frequency of impacts [87,90]. The higher body mass and frequency of engagement of forwards in contact situations, including pushing in scrums and jumping and supporting in line-outs, increase the osteogenic mechanical stimuli compared with backs. As with the other tissues, higher bone mineral mass in forwards than backs may be explained by the combination of selection of playing position based on genetic predisposition and adaptation to the specific role requirements of competition.

**Conclusion**

While forwards have a greater quantity of fat, lean and bone mass than backs in both rugby union and rugby sevens, the magnitude of difference between the positional groups is greater in rugby union players. These differences likely represent variation in the physical demands of competition between positional groups in each rugby format. When regional tissue mass is expressed as a proportion of total regional mass, positional group differences persist in rugby union players, but become predominantly unclear in rugby sevens players. It appears the advantage of higher body mass gained through an increase in absolute fat mass and proportional decrease in non-osseous lean mass in international rugby union forwards is greater than any potential detriment to physical performance and work capacity. Achieving the ideal ratio of fat and lean mass in each anatomical region should contribute to optimal physical performance. The most effective absolute and relative tissue masses vary between rugby formats, positions and individuals. Competing at the international level in rugby union or rugby sevens characterises the distribution of fat and non-osseous lean mass to a greater extent than a player’s positional group. However, the distribution of bone mineral mass is associated more with a player’s position than the rugby format in which they compete.
Chapter Nine - Comparison of Activity Profiles and Physiological Demands between International Rugby Sevens Matches and Training


Abstract

The specificity of contemporary training practices of international rugby sevens players is unknown. We quantified the positional group-specific activity profiles and physiological demands of on-field training activities and compared these to match demands. Twenty-two international matches and 63 rugby-specific training drills were monitored in 25 backs and 17 forwards from a national squad of male rugby sevens players over a 21-month period. Drills were classified into three categories: low-intensity skill-refining (n = 23 drills, 560 observations), moderate- to high-intensity skill-refining (n = 28 drills, 600 observations), and game-simulation (n = 12 drills, 365 observations). Movement patterns (via GPS devices) and physiological load (via heart rate monitors) were recorded for all activities and differences between training and matches quantified using magnitude-based inferential statistics. Distance covered in total and at ≥3.5 m·s⁻¹, maximal velocity, and frequency of accelerations and decelerations were lower in forwards during competition compared with backs by a small but practically important magnitude. No clear positional group differences were observed for physiological load during matches. Training demands exceeded match demands only for frequency of decelerations of forwards during moderate- to high-intensity skill-refining drills and only by a small amount. Accelerations and distance covered at ≥6 m·s⁻¹ were closer to match values for forwards than backs during all training activities, but training drills consistently fell below the demands of international competition. Coaches could therefore improve physical and physiological specificity by increasing the movement demands and intensity of training drills.

Key words: Global Positioning System, GPS, rugby union, time-motion analysis, physical preparation, specificity
Introduction

Success in rugby union and the abbreviated rugby sevens format requires a high degree of skill, tactics and physical ability. The efficacy of practice and training interventions on factors related to rugby performance is well established [4,110,126,138]. However, the physical and physiological demands and specificity of individual training drills are largely unknown. Training drills are often designed with a specific learning or adaptation objective, such as strength and conditioning, skill development, tactical team play, or a combination thereof. Match-specific drills simulating game scenarios are designed to prepare players for the physiological, skill, and decision-making demands of competition. The development of all facets of performance including skill, decision-making, fitness, and team structures warrant dedicated training time. An overemphasis on training these facets in isolation could limit the opportunities for match-specific drills that purportedly replicate physical and tactical competition demands using appropriate work-to-rest ratios. Despite the ostensible advantages of match-specific training, it is unrealistic and potentially undesirable for training to consistently reproduce match loads [70]. The positive relationship between on-field training loads and injury rates observed in professional contact team sports highlights the need to minimise the risks to players’ health and performance without compromising training adaptations [105].

The capability to define and monitor the demands of training and competition in team sports has improved as a result of measurement techniques such as Global Positioning System (GPS) technology [103,200]. Portable micro-technology worn by players now allows for heart rate, physical impacts, distance and velocity to be quantified without interference to the training and match environment [12]. Comparisons of training and competition demands have been examined in several team sports, including field hockey [103], volleyball [101], soccer [107], cricket [200], rugby league [106] and Australian football [70]. Research comparing the demands of training and matches in rugby union is limited to a single study of adolescent players [128]. The demands of competition and requirements for physical development in international rugby sevens are unique [132,133], yet the effectiveness and specificity of training of rugby sevens players remain unclear. An investigation of contemporary training practices is required to assist development of approaches that consider the duration, volume, intensity and frequency of training relative to the athlete’s needs and phase of the season. Understanding the activity profile and demands of various training drills, and quantifying the disparity between training and match demands, provide a useful scientific framework for
coaches to prescribe periodised training programmes. Therefore, the purpose of this study was to quantify the positional group-specific (backs and forwards) activity profile and physiological demands of different types of rugby sevens training activities and compare them with the demands of competition.

**Methods**

**Experimental Approach to the Problem**

A prospective, longitudinal, observational study was conducted to characterise the physical and physiological demands of training activities of a national rugby sevens team. Team members had their movement patterns and heart rate recorded throughout various drills during on-field training sessions. The demands of training activities were then compared with the demands of a sample of international-level matches played by the same players during the data collection period.

**Participants**

Forty-two male rugby sevens players from a national team that competes as a core (top 15) team in the International Rugby Board (IRB) Sevens World Series provided written informed consent and volunteered to participate in the study. Players were classified as either forwards (n = 17, age 21.6 ± 2.4 years, height 1.85 ± 0.05 m, body mass 95.8 ± 6.7 kg; mean ± SD at the start of data collection) or backs (n = 25, age 21.0 ± 2.2 years, height 1.81 ± 0.06 m, body mass 86.2 ± 5.6 kg) based on their primary playing position. Results are only reported for players free of injury and illness during match and training activities. The study was approved by the University of Canberra Committee for Ethics in Human Research and Australian Institute of Sport Ethics Committee.

**Procedures**

Sixty-three on-field training sessions were monitored over a 21-month period. Data were collected on 63 training drills. Drills were classified by the coaches and team physiologist into one of three types of training activity based on the primary purpose and perceived physical intensity of the drill: low-intensity skill-refining (n = 560 observations during 23 drills), moderate- to high-intensity skill-refining (n = 600 observations during 28 drills), and game-simulation (n = 365 observations during 12 drills). Skill-refining drills aimed to improve technical aspects of match play, such as tackling and rucking technique, defensive line shape and speed, set-piece play, and passing and catching ability. Game-simulation drills
were designed to practice skills and tactical aspects of play under match-like conditions. The study was delimited to rugby-specific training activities with the ball. Therefore, conditioning drills and warm-up activities were excluded from analyses. Training activities were compared with data from 22 matches collected on the same group of players during four international tournaments (IRB Sevens World Series and Federation of Oceania Rugby Unions Oceania Sevens Championship) played during the data collection period (n = 306 observations). Any training or match observation with a duration <1 min was excluded from analysis. Matches were split by each half, and the half-time interval and any time a player spent off the field were excluded. Each match half, or part thereof, was treated as a single observation. Although differences in the movement patterns between first and second halves, matches within a tournament, and full-match and substitute players are evident and acknowledged [132], match activities and demands were characterised by the mean of all observed competition data.

Activity profiles were assessed during training and matches by fitting players with a portable GPS device sampling at 15 Hz (SPI Pro X, GPSports Systems, Canberra, Australia). The validity and reliability of GPS micro-technology for monitoring sports performance have been reviewed previously [65]. Physiological demands were assessed during selected training activities by fitting players with a heart rate transmitter strap (T34, Polar Electro Oy, Kempele, Finland). Heart rate data were recorded to the GPS device at 1 Hz. The GPS device was positioned between the scapulae of each player using a vest worn underneath the training or match attire. The unit was activated and satellite lock established for a minimum of 10 min before the commencement of each session. All players were familiar with the data collection procedure. After each session, recorded data were analysed using the manufacturer’s software (Team AMS release 1 2011 revision 8, GPSports Systems, Canberra, Australia).

Activity profiles were quantified by the frequency of efforts and cumulative distance covered in five velocity zones (0 to 2 m·s⁻¹, 2 to 3.5 m·s⁻¹, 3.5 to 5 m·s⁻¹, 5 to 6 m·s⁻¹ and ≥6 m·s⁻¹) [132]. Acceleration and deceleration characteristics were assessed by the frequency a player performed an acceleration (≥1 m·s⁻²) or deceleration (≤-1 m·s⁻²) for a minimum duration of 1 s. The frequency and intensity (reported in gravitational (g)-force) of mechanical loading (impacts) on players was recorded by a 100 Hz tri-axial accelerometer housed within the GPS device. Given the questionable validity of accelerometers in quantifying the contact loads on athletes [104], the total number of impacts measured at ≥5 g was measured instead of categorising impact measurements by magnitude as has been reported previously [68]. A
magnitude of ≥5 g encompasses a range from a light impact characterised by a heavy foot-strike during a rapid acceleration, deceleration, or change of direction to a severe collision with opposition players [68].

Mean and peak heart rate measured during training drills and matches were recorded. Heart rate data were categorised into five zones corresponding to the percentage of each player’s maximum heart rate (HRmax) recorded during the Yo-Yo intermittent recovery level 1 test [20], or an incremental running test on a motorised treadmill. Maximum heart rate values were subsequently updated if the testing values were exceeded during training or a match. The cumulative time in five heart rate zones was multiplied by a weighting factor (50 to 59% HRmax = 1, 60 to 69% HRmax = 2, 70 to 79% HRmax = 3, 80 to 89% HRmax = 4, and ≥90% HRmax = 5) to linearly scale the intensity of activity. The adjusted values were then summed to indicate the cardiovascular load in arbitrary units [86]. An index describing the efficiency of movement with respect to the relative internal load on the player, termed the performance efficiency index and measured in arbitrary units, was calculated for each training drill and match half as the relative distance covered (m·min⁻¹) per %HRmax [21].

**Statistical Analyses**

Most movement and heart rate variables were expressed per min of activity time to account for variations in match and training duration. Descriptive statistics (mean ± SD) are reported to characterise movement patterns and physiological load. Variability within players was calculated as the mean of each player's SD, while differences between players in activity and physiological load parameters were calculated as the SD of all observations. These SD were expressed as coefficients of variation (percents of the overall means). Standardised differences in the means of the various training activities and match demands for each positional group were used to assess magnitudes of effect by dividing the differences by the between-player SD. Magnitudes of standardised differences in means were assessed with the following scale: 0 to 0.2 trivial, 0.2 to 0.6 small, 0.6 to 1.2 moderate, 1.2 to 2.0 large, 2.0 to 4.0 very large, and ≥4.0 extremely large [141]. To address the issue of quantification of longitudinal changes in performance characteristics, the signal-to-noise ratio of each variable for both positional groups during each activity was calculated as 0.2 × between-player SD/within-player SD.

Precision of the estimate of the difference is shown with a confidence interval derived as the appropriate percentiles of 3000 bootstrapped sample values. Bootstrapping was used because
a mixed linear model did not converge on a solution in less than a day for each variable. To reduce the likelihood of errors about inferred magnitudes, 99% was chosen as the level for the confidence intervals. A difference was reported as unclear when the confidence interval of the standardised difference crossed the threshold for both substantially positive (0.2) and negative (-0.2) values. Analyses were performed with the Statistical Analysis System (version 9.2, SAS Institute, Cary, NC).

**Results**

**Differences between Positional Groups**

Backs recorded higher values than forwards during matches in most movement variables, but there were unclear differences between positional groups in physiological demands represented by heart rate parameters (Table 9.1). The difference in relative impacts between groups was also unclear. The higher total relative distance covered by backs was due to the small difference in the frequency of entries and relative distance covered in velocity zones $\geq 3.5 \text{ m}\cdot\text{s}^{-1}$. The small difference in distance covered at a similar relative heart rate resulted in a moderately higher performance efficiency index in backs than forwards. The within-player coefficient of variation of movement and physiological measures ranged from 2.6% for peak heart rate in forwards during matches to 210% for relative distance covered at $\geq 6 \text{ m}\cdot\text{s}^{-1}$ in forwards during low-intensity skill-refining drills. The coefficient of variation for between-player differences ranged from 3.2% for peak heart rate in forwards during matches to 280% for relative distance covered at $\geq 6 \text{ m}\cdot\text{s}^{-1}$ during low-intensity skill-refining drills, also in forwards. The signal-to-noise ratio ranged from 0.19 (that is, the noise was ~five-fold greater than the signal) in the frequency of entries in the 3.5 to 5 m·s⁻¹ velocity zone per min in forwards during moderate- to high-intensity skill-refining drills to 0.43 in relative impacts during matches in backs.
Table 9.1. Movement and physiological load variables (mean ± SD) for forwards (n = 14 players, 162 observations) and backs (n = 18 players, 144 observations) during 22 international rugby sevens matches.

<table>
<thead>
<tr>
<th></th>
<th>Forwards</th>
<th>Backs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total distance (m·min⁻¹)</td>
<td>96 ± 12</td>
<td>103 ± 14*</td>
</tr>
<tr>
<td>Maximal velocity (m·s⁻¹)</td>
<td>7.5 ± 0.9</td>
<td>8.0 ± 1.1*</td>
</tr>
<tr>
<td>Impacts (min⁻¹)</td>
<td>26.2 ± 10.7</td>
<td>23.5 ± 9.6</td>
</tr>
<tr>
<td>Accelerations (min⁻¹)</td>
<td>3.6 ± 0.9</td>
<td>4.1 ± 1.1*</td>
</tr>
<tr>
<td>Decelerations (min⁻¹)</td>
<td>2.9 ± 0.7</td>
<td>3.2 ± 0.9*</td>
</tr>
<tr>
<td>Mean heart rate (% of maximum)</td>
<td>86.9 ± 4.5</td>
<td>85.0 ± 5.3</td>
</tr>
<tr>
<td>Peak heart rate (% of maximum)</td>
<td>94.8 ± 3.0</td>
<td>93.8 ± 4.0</td>
</tr>
<tr>
<td>Cardiovascular load (min⁻¹)</td>
<td>4.2 ± 0.4</td>
<td>4.0 ± 0.5</td>
</tr>
<tr>
<td>Performance efficiency</td>
<td>1.09 ± 0.12</td>
<td>1.22 ± 0.20†</td>
</tr>
<tr>
<td>Velocity zone entries (min⁻¹)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 to 3.5 m·s⁻¹</td>
<td>7.9 ± 1.9</td>
<td>8.4 ± 2.1</td>
</tr>
<tr>
<td>3.5 to 5 m·s⁻¹</td>
<td>4.5 ± 1.2</td>
<td>5.1 ± 1.5*</td>
</tr>
<tr>
<td>5 to 6 m·s⁻¹</td>
<td>1.9 ± 0.8</td>
<td>2.3 ± 1.1*</td>
</tr>
<tr>
<td>≥6 m·s⁻¹</td>
<td>0.6 ± 0.4</td>
<td>0.8 ± 0.5*</td>
</tr>
<tr>
<td>Distance in velocity zones (m-min⁻¹)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 to 2 m·s⁻¹</td>
<td>33.7 ± 7.1</td>
<td>33.2 ± 5.4</td>
</tr>
<tr>
<td>2 to 3.5 m·s⁻¹</td>
<td>25.7 ± 6.8</td>
<td>26.5 ± 6.6</td>
</tr>
<tr>
<td>3.5 to 5 m·s⁻¹</td>
<td>20.9 ± 6.3</td>
<td>23.3 ± 7.4*</td>
</tr>
<tr>
<td>5 to 6 m·s⁻¹</td>
<td>8.9 ± 4.8</td>
<td>10.2 ± 6.2*</td>
</tr>
<tr>
<td>≥6 m·s⁻¹</td>
<td>6.4 ± 5.1</td>
<td>9.8 ± 6.6*</td>
</tr>
</tbody>
</table>

Clear positive difference compared with forwards: *small, †moderate.

Differences between Training Activities and Matches

Maximal velocity, and relative values of impacts, distance covered, accelerations and decelerations in training were either unclear or lower (small to extremely large differences) compared with matches (Figure 9.1). The only measure to substantially exceed match values was decelerations in moderate- to high-intensity skill-refining drills in forwards. Moderate- to high-intensity skill-refining drills and game-simulation drills had values closer to match values than low-intensity skill-refining drills in all variables.
Figure 9.1. Standardised differences in activity profiles between training activities and international rugby sevens matches. Error bars represent 99% confidence limits. Shaded region represents a trivial difference. LI skill = low-intensity skill-refining; HI skill = moderate- to high-intensity skill-refining; Game Sim = game-simulation; B = backs; F = forwards.

**Differences in Velocities**

Less relative distance was covered in training drills compared with matches in all velocity zones (small to very large differences, Figure 9.2). Less relative distance was covered at all velocities in low-intensity skill-refining drills compared with moderate- to high-intensity skill-refining and game-simulation drills (small to large differences).
Differences in Physiological Load

The mean and peak heart rate, cardiovascular load, and performance efficiency index did not replicate the demands of international matches for backs and forwards during all training activities (moderate to extremely large differences, Figure 9.3). Training values were closer to match values for backs than forwards in all drill types and variables except for performance efficiency during moderate- to high-intensity skill-refining drills.
**Discussion**

The ultimate objective of a physical preparation programme is to maximise training adaptations to prepare players for optimal competition performance. Training specificity is usually achieved through on-field training approaches that aim to match or exceed the technical, tactical, physical, physiological, and psychological demands of top-level competition. This study is the first to directly compare the activity profiles and physiological demands of backs and forwards during international rugby sevens competition, and assess the positional group-dependant specificity of training activities. Small but practically important differences in movement patterns were observed between backs and forwards during competition. Compared with forwards, backs achieved a higher maximal velocity, performed more accelerations and decelerations, and covered greater distances at $\geq 3.5 \text{ m} \cdot \text{s}^{-1}$ and overall. However, these differences in activity were not accompanied by a corresponding difference in physiological load.

A major finding of this study was the substantial disparity in the activity profiles and internal load of all forms of rugby-specific on-field training activities and international matches.
Relative to competition, training was characterised by less distance covered (large to extremely large differences), similar or lower maximal velocities (unclear to very large differences), less impacts (moderate to large differences), and similar or fewer accelerations (unclear to large differences). There were also fewer decelerations in training compared with matches for all training activities except for forwards during moderate- to high-intensity skill-refining drills. Heart rate-based indicators of the physiological load of training activities were lower than during matches. Marked differences between some training practices and competition should be expected, given that consistently reproducing match demands during training would oversimplify the complex multifaceted factors associated with development of elite rugby players [81]. Even so, the findings of this study provide important information that may be used to implement strategies that emphasise the specificity of movements and conditioning stimuli during training.

Differences in activity profiles between backs and forwards during matches support the need for position-specific training approaches. Position-specific training is likely to occur to some extent as players typically train in the positions in which they will compete. Positional differences in the total distance covered and the distance travelled at high velocity during competition are consistent with similar observations in 15-player professional rugby union competition [13,54,68,220]. Although the specificity of movement pattern parameters varied between positional groups in training, the physiological load of forwards during training was consistently lower relative to matches compared with backs. It is uncertain whether the higher values of movement variables for backs compared with forwards during international competition reflect greater demands related to differences in positional roles, higher fitness levels of backs, or a combination of these factors. The unclear differences during matches in the physiological load and distance covered at lower velocity (<3.5 m·s⁻¹) between backs and forwards imply lower match-specific fitness of forwards may be an explanation for positional variations in activity profiles. Indeed, backs performed marginally better than forwards in the Yo-Yo intermittent recovery level 1 test (2202 ± 288 vs. 2093 ± 389 m; mean ± SD), a measure of team sport-specific endurance [20].

Despite a lower cardiovascular load, accelerations and distance covered at ≥6 m·s⁻¹ were closer to match values for forwards than backs during all training activities. The same trend was observed for maximal velocity during all training activities except low-intensity skill-refining drills. The variation in maximal velocity achieved in low-intensity skill-refining drills may be explained by training drills devoted to set-piece plays with minimal
involvement from backline players. Technical drills practicing scrums and line-outs typically involve little to no maximal sprinting.

The acceleration and deceleration of a player’s body mass increases the mechanical load and metabolic cost of exercise compared with running the same distance at a constant velocity [142,196]. Disregarding the frequent changes in running velocity likely underestimates the true quantity of high-intensity activity of team sport athletes [166]. Frequency of decelerations of forwards during moderate- to high-intensity skill-refining drills was the only measure to substantially exceed match demands. Similarly, physical impacts, either through contact with the ground or other players, increase the mechanical load on players, concomitantly increasing the time required for recovery from muscle damage and soreness [111,245,251]. The lower frequency of impacts of ≥5 g in training reflects the combination of reduced high-velocity running volumes that result in a forceful foot-strike and limited exposure to “full contact” drills, which increase recovery requirements and potential for injury [41].

The analysis of training specificity in this study excluded only the periods between training drills for drinks breaks, and time allocated for drills to be set up and explained. At least part of the reduced activity and physiological demands of training compared with competition may be explained by the intermittent breaks in activity within a drill for coaching feedback and instruction. We chose to include these breaks within drills in our analyses to reflect the actual physical and physiological demands experienced by players. The other factor that may contribute to the lower physical and physiological load of training is the use of “closed” drills, whereby technical development is emphasised through high repetition of skill executions typically without a decision making component. Closed drills may permit additional recovery time between activity periods while players wait for their turn to perform a task. In contrast, “open” drills simulating match-like conditions are more physically and cognitively demanding [92].

The planning of training programmes for international rugby sevens players is influenced by a multitude of factors, including the phase of season and proximity of training to competition; ground firmness and environmental conditions; effects of interstate and international travel; perceived intensity of previous and upcoming competitions; and team and individual considerations, such as fitness and form [70]. Despite the importance of these and other considerations, match-specific drills should aim to replicate or exceed match demands to best
prepare players for the requirements of competition [70]. The game-simulation drills observed in this study failed to reproduce the physical or physiological demands of matches. The low specificity of skill-refining drills may be expected, given their lack of explicit emphasis on conditioning. Unsurprisingly, of the three training activities, low-intensity skill-refining drills were least reflective of match conditions in every variable measured. Subsequent analyses of the standardised differences between training activities with respect to positional groups showed low-intensity skill-refining drills were substantially lower than moderate- to high-intensity skill-refining and game-simulation drills for all variables (results not shown). In contrast, differences between moderate- to high-intensity skill-refining and game-simulation drills were smaller and more variable. Small standardised differences were observed for some variables, although most comparisons showed unclear to trivial differences (results not shown). Differences in these training activities may be better reflected by quantifying the technical and tactical requirements of training drills rather than the physical and physiological demands alone.

Investigation of the frequency and quality of technical components of match-play, such as passes, tackles, kicks, set-piece plays, and decision-making ability, was not within the scope of the current investigation. Future research should investigate the specificity of the technical and tactical components of rugby sevens training and examine strategies that maximise skill learning. It is possible there is a compromise between the training time required for optimal physical and technical development in international rugby sevens players. However, given the potential impact of fatigue on the execution of physical and cognitive skills [102,220], training outcomes may be enhanced by the practice of skills under conditions that simulate the high-intensity activity of competition. The optimal balance and timing of instructional skills training and match-specific drills, either in isolation or combination, to maximise the physical and technical development of rugby sevens players also requires further research.

The lower intensity of training may lead to sub-optimal or inappropriate adaptation of the metabolic pathways utilised during competition. The lower internal load of training, as indicated by heart rate-based measures, is likely to result in a greater emphasis on the aerobic system. International rugby sevens players require well-developed aerobic endurance to tolerate the demands of competition and facilitate rapid recovery within and between matches [133]. However, the development of anaerobic systems to support short-duration, high-intensity activity, such as sprinting, should not be neglected. The ability to quickly recover from and repeat performances of high-intensity activity is important in team-sport
competitions [112], especially in rugby sevens. The training specificity of repeated bouts of high-intensity exercise is also critical, given the task-dependent nature of physiological adaptations to the performance of this activity. It is unlikely the consistently lower frequency of, and distance covered during, high-velocity (≥6 m·s⁻¹) running observed in training compared with matches offers a sufficient stimulus for optimal adaptation to meet competition demands.

Mean and peak heart rate and cardiovascular load discriminated independently each training activity with the exception of moderate- to high-intensity skill-refining and game-simulation drills (results not shown). However, one could not be confident about quantifying trivial or small changes in the intensity of drills between sessions, owing to the inherent noise of heart rate metrics (evident in the relatively poor signal-to-noise ratios). To longitudinally track an individual player or assess an intervention with a repeated-measures design using realistic sample sizes, several sessions would need to be monitored and averaged to reduce the within-player variability to a value comparable with the smallest important change (a signal-to-noise ratio of ~1.0). The most reliable measure in this study, the frequency of impacts during matches, would require six repeated observations to quantify trivial changes confidently, and other measures would require several times more.

The findings of this study highlight the potential to improve the training efficiency of international rugby sevens players. Training efficiency can be improved through greater physical specificity for a superior return from on-field training time without compromising a player’s health or performance. Rugby players are often exposed to high training volumes during the pre- and in-competition training phases [41]. There is an association between training load and incidence of injuries [105] and between training volume and injury severity [41] in professional contact team sports. However, a professional rugby union team’s training volume does not significantly correlate with their final competition ranking [41]. Furthermore, a reduction of pre-season training volume in sub-elite rugby league players lowered injury rates without any detrimental effect on training adaptations [100]. The effect of reducing training volumes on training adaptations, incidence and severity of injuries, and recovery requirements in rugby sevens players is yet to be determined. Nevertheless, the results of our analysis support the assertion that modifying training approaches to improve efficiency may simultaneously reduce the risks associated with high training volumes while maintaining or improving training adaptations.
Practical Applications

Specificity of training is an important consideration for prescription of physical preparation programmes to promote physiological adaptations for the benefit of competition performance. The training activities in this squad over 21 months did not replicate the physical or physiological demands of top-level competition. Although it may be undesirable for technically-focused drills to reproduce the physical loads of competition, game-simulation drills should reflect match demands to adequately prepare players for competition. Understanding the demands of competition facilitates the modification of match-specific training drills to improve specificity and adopt position-specific training approaches. The magnitude-based approach used in this study highlights the priorities for improving the specificity of movement patterns and velocities based on a player’s position and the type of training drill. For example, although the maximal running velocity achieved by forwards during game-simulation drills was similar to competition, the mean velocity (m·min⁻¹) was substantially lower. Coaches could improve the management of their players’ training load and enhance training efficiency by increasing intensity and specificity and reducing training duration. Furthermore, coaches should consider the influence of interruptions in training activity for instruction and feedback on the movement patterns and physiological load imposed on players. Heart rate monitoring provides a useful index of a player’s internal response to a training stimulus to ensure the appropriate adaptations are achieved, while GPS devices provide an objective external measure of the work performed by a player. Monitoring the activity profile and physiological load of training activities should ensure training drills optimally prepare players for the demands of competition.

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Chapter Ten – Discussion

To achieve success at the international level, player development and team preparation strategies in rugby sevens should be holistic and consider, in isolation and collectively, the technical, tactical, physical and physiological requirements for competition. Through a systematic series of studies relating to the analysis of competition and requirements for player selection and development, it is apparent that the demands of international-level rugby sevens competition are distinct from 15-player rugby union. Successful player- and team-preparation programmes need to acknowledge these differences and structure training plans based on specific development objectives.

Rugby sevens is a tactical, physically-demanding, and skill-based team sport. Consequently, success at the elite level requires sustained emphasis on developing and maintaining the physical qualities and technical abilities of players. The first stage of constructing an effective player- and team-development framework was to accurately define the technical, tactical, and physical demands of competition (Chapter Three to Chapter Six). The second step was to define the characteristics of international-level players to determine the priorities for physical development (Chapter Seven and Chapter Eight). Finally, training methods to improve the physical qualities of players can be implemented, monitored and refined to ensure the training programme is specific and efficient in preparing players for competition (Chapter Nine).

Technical and Tactical Requirements of Competition

The use of notational analyses to quantify the technical and tactical components of competition from a large sample of matches and tournaments provides coaches and support staff with a contemporary profile of rugby sevens. Moreover, relating the technical and tactical elements of competition with team success assists in defining the requirements of the sport. Given rugby sevens is played in a tournament format and the IRB Sevens World Series is the pre-eminent international competition, the requirements for competition were described not only by the factors contributing to winning a single match (Chapter Three), but also success in a tournament (Chapter Four) and across the entire World Series (Chapter Five). Such information allowed the priorities for technical development of individual players and teams to be identified and informs tactical approaches to competition directed by coaches.
The studies presented in this thesis highlight differences in technical and skill components between rugby sevens and rugby union, and between successful and unsuccessful teams. Although most performance indicators exhibited a high degree of variability between matches, tournaments and World Series, many were substantially related to a team’s performance and subsequent relative success (Chapter Three to Chapter Five). Analysis of large samples and the averaging of team performances to quantify between-team effects attenuate the variability or noise of the relationship between individual match performances and success, strengthening the observed associations (Chapters Four and Chapter Five). Such analyses emphasise priority areas for team development and longitudinal performance monitoring. Rugby sevens performance at the elite level is dependent not only on the attainment and repeated execution of high levels of technical skill from individual players, but also the interaction, cohesion and tactical approach of teams. Player development programmes must target individual skills necessary for rugby sevens, such as passing, tackling and contesting the breakdown, as well as team tactics that employ the collective technical strengths of the team and exploit weaknesses of the opposition.

The importance of set-piece plays in rugby sevens in determining a single match outcome is lower than in rugby union. While the number of scrums and line-outs in a rugby sevens match is less than in rugby union, the reduced number of players and variations in the laws of the game diminish the ascendancy in territory and possession a team can gain by dominating set-piece plays. Instead, teams most likely to score points and win rugby sevens matches control ball possession, not only at the line-out, but by more frequently avoiding contact and retaining a greater proportion of possession at the breakdown. Despite the variable and high-tempo nature of rugby sevens, teams most likely to win closely-contested matches play a patient and evasive style of game (Chapter Three).

Over the course of a tournament or an annual World Series, other skills and tactics are important in determining a team’s relative success. Within a tournament, successful teams maintain ball possession by having fewer errors and surrendered possessions per match, and are more efficient in converting possession into tries. The importance of effective tackling ability and defensive systems in determining a team’s success is highlighted by the fewer missed tackles and more completed tackles, resulting in a higher rate of tackle completion, in better-performing teams (Chapter Four). Consequently, to increase the chances of success at the international level, team preparation should give attention to both offensive and defensive factors of performance.
When match statistics were aggregated from teams during multiple matches and tournaments, a team’s effectiveness in gaining or maintaining the ball at the breakdown emerged as a key discriminating factor of a team’s relative success (Chapter Five). Technical development programmes should therefore accentuate the ability of players to contest ball possession at the ruck. Notably, conceding more penalties and free kicks was related to a lower number of points scored in a single match, but had a trivial effect on a team’s likelihood of winning a close match (Chapter Three). In contrast, conceding more penalties and free kicks had a beneficial association with a team’s World Series ranking (Chapter Five). It appears more-successful teams are not necessarily more disciplined, but instead may be more discretionary or selective in the period of the match or area of the field in which a penalty or free kick is conceded.

Movement Patterns and Physiological Demands of Competition
Comprehensively detailing the physical loads on players during competition is a crucial step in prescribing training to enhance the appropriate physical attributes of players. The short-duration, high-intensity tournament format of rugby sevens yields different movement patterns and physiological demands of competition than rugby union. The activity profiles of and demands on players correspond to having fewer players on the rugby sevens field relative to rugby union. As a result, rugby sevens players cover ~20 to 45% greater distance relative to the match duration, with a higher proportion of total distance covered at high velocity (Chapter Six and Chapter Nine). During a full match, rugby sevens players cover ~1400 to 2000 m at a mean intensity of 96 to 120 m·min⁻¹. The different style of competition (multi-day tournament vs. seasonal league) and increased relative movement volume and intensity in rugby sevens matches warrant different approaches to training and priorities for the physical development of players.

Although differences in the positional roles and movement patterns of backs and forwards during matches are less pronounced in rugby sevens than rugby union (Chapter Nine), these differences should be considered when prescribing a player’s training programme. Relative to forwards, backs achieve a higher maximal velocity, perform more accelerations and decelerations, and cover greater distances overall and at ≥3.5 m·s⁻¹. However, the differences in activity are not accompanied by corresponding differences in heart rate measures of internal load (Chapter Nine). Despite the requirement for individually-prescribed training programmes for each player based on their position-specific requirements for physical
development, the relatively low between-player variability in anthropometric, physical, and performance qualities observed in a national squad of rugby sevens players highlights the need for more uniform physical and performance objectives or benchmarks compared with rugby union players (Chapter Seven and Chapter Eight).

International-level matches are played at a higher intensity than domestic-level matches and elicit a greater physical load on players (Chapter Six). Despite this observation, analyses of domestic and international match demonstrate a 1 to 16% reduction in a player’s work-rate from the first to second half (Chapter Six). The small reduction is most likely the result of fatigue as players are unable to sustain high-intensity activity. The diminished work-rate of players in the latter stages of a match highlights the importance of developing endurance and fatigue resistance in players. Given the small number of players on the field for a rugby sevens team, decrements in a player’s ability to maintain high-intensity activity could have a substantial detrimental effect on team performance. Conversely, tactical substitution of a player at a crucial stage of a match may positively influence a team’s work-rate and have a decisive effect on a match outcome (Chapter Six).

Rugby sevens matches are characterised by repeated bouts of high-intensity activity. Approximately 16 to 19% of the distance covered in an international match is at a velocity exceeding 5 m·s\(^{-1}\) with players attaining mean match heart rates of ~86% of maximum (Chapter Six and Chapter Nine). To increase the potential for success in a rugby sevens tournament, players must be able to consistently reproduce high-intensity efforts in multiple matches over successive days. This requisite has implications for the moderate- to long-term physical development of players, as well as short-term requirements for recovery between matches to mitigate the effects of transient and residual fatigue. Training methods to enhance a rugby sevens player’s ability to perform repeated bouts of high-intensity activity with limited recovery should include task-specific drills, such as high-intensity interval training and game-simulation drills, as well as interventions to address the primary factors limiting performance [32]. Additionally, strategies that promote recovery between matches, such as nutritional interventions (Appendix A), cryotherapy, and contrast water therapy or cold water immersion [111,255] may also be beneficial.

**Characteristics and Capacities of Rugby Sevens Players**

Evaluating the characteristics and functional capacities of players in both the field and laboratory (Chapter Seven and Chapter Eight) complements information gained through the
quantification of competition demands (Chapter Six and Chapter Nine). These assessments give immediate feedback to coaches and support staff that is useful for training prescription, as well as informing long-term player selection and development of junior athletes. The characteristics of international-level players and the programmes to develop these characteristics are dictated primarily by the demands of competition. The high-intensity and collision-based nature of rugby sevens with relatively high running volumes suggests successful players need well-developed strength, power, speed and endurance qualities.

The enhancement of a player’s endurance, specifically their aerobic capacity, is likely to assist with the recovery from high-intensity activity within and between matches. A higher level of fitness may also reduce the risk of injury [99] and susceptibility of players to fatigue-related errors in skill execution [102]. The relative VO$_2$max of international rugby sevens players is similar to or greater than that of professional and international rugby union players (Chapter Seven). However, other metabolic and neural factors, such as creatine phosphate resynthesis, anaerobic capacity, hydrogen ion buffering, and muscle excitability and recruitment, also contribute greatly to players’ abilities to perform repeated high-intensity exercise [112]. Measuring performance related to these factors collectively through repeated-sprint ability and sport-specific endurance tests highlights the need for rugby sevens players to develop anaerobic capacity and endurance in combination with aerobic fitness (Chapter Seven).

Both acceleration and maximal velocity qualities are fundamental to successful international-level rugby sevens players. During international matches, backs covered 9.8 ± 6.6 m·min$^{-1}$ (mean ± SD) and forwards, 6.4 ± 5.1 m·min$^{-1}$ at ≥6 m·s$^{-1}$ (Chapter Nine). In domestic-level matches, backs and forwards covered maximal distances at >5.6 m·s$^{-1}$ of 44.5 ± 14.4 m and 37.5 ± 10.0 m, respectively [239]. International players possess acceleration abilities similar to or exceeding those of elite rugby union players and maximal straight-line sprint velocity values comparable to those of professional rugby union backs (Chapter Seven). To develop speed and acceleration qualities, rugby sevens players should be exposed to speed training during team-based skill drills. Although, given the importance of this characteristic for success in competition, rugby sevens players may benefit from supplementary specific speed sessions that focus on developing acceleration and maximal velocity qualities. Furthermore, in addition to improving running technique and strength characteristics specific to sprinting, training drills should also incorporate a variety of starting speeds to replicate the movement
patterns of competition [83], as well as the fundamental abilities to catch, pass, and run with the ball [116,268].

On average, modern male rugby sevens players are shorter, lighter and leaner than their rugby union counterparts (Chapter Seven). Given the smaller differences in movement patterns and increased need for mobility in all rugby sevens positions, differences in physique between rugby sevens backs and forwards are less pronounced than positional differences of rugby union players (Chapter Eight). Differences in anthropometric attributes of rugby sevens and rugby union players presumably reflect the lower demands for physical confrontation (Chapter Eight) and higher running demands in rugby sevens (Chapter Six). Although a lighter body mass may be beneficial for performing frequent sprints, accelerating, decelerating, and changing direction when running, a higher body mass is advantageous during contests for the ball. Rugby sevens players should develop a proportionally high muscle mass that assists in force production required for accelerating, sprinting, effecting and breaking tackles, and during rucks and mauls (Chapter Eight). Players should simultaneously attempt to limit fat mass, which can compromise their power-to-weight ratio, metabolic efficiency [277] and thermoregulation [230].

Although a relatively light and lean physique may be advantageous in rugby sevens, anthropometric characteristics of international rugby union players suggest a higher body mass, potentially at the expense of leanness, may increase a player’s momentum and be beneficial for the increased contact demands of rugby union (Chapter Eight). Indeed, the quantity and regional anatomical distribution of fat, non-osseous lean and bone mineral mass are characterised by both the positional roles and specific demands of rugby union and rugby sevens (Chapter Eight). The transition of players between rugby union and rugby sevens may result in conflicting physique requirements and subsequent training and nutritional strategies. Conversely, information on the regional and whole-body size and composition characteristics of international-level players may assist in selecting players into the rugby format and/or position to which they are best physically suited. Information on physique traits that characterise both international-level rugby sevens and rugby union players presented in this thesis (Chapter Eight) provides an important step in understanding differences in body composition associated with different positional groups and rugby formats.
**Physical Training and Player Development**

The multitude of technical (Chapter Three to Chapter Five) and physical (Chapter Six to Chapter Eight) qualities required for success in rugby sevens underline the challenge of developing a programme to prepare international-level players for competition. The fundamental goals of the development programme are to increase a player’s skill level and work capacity; improve strength, power and speed; and optimise body size and composition specific to positional demands. Ideally, these outcomes are achieved in an efficient and timely manner that minimises the risk of injury, illness, and overtraining. Establishing the priorities for team and individual player preparation is a prerequisite for the prescription of a training and preparation programme. Priorities should be based on the requirements of the annual competition schedule, the rates of adaptation to training, the timeframe for player development, and assessment of an individual player’s strengths and weaknesses.

Accompanying the increase in profile and international competitiveness of rugby sevens [45] is a parallel increase in the professionalism and specialisation of athletes in the sport. Although it is still common for many players to compete in both rugby sevens and rugby union, the demands of training and competition and the differing competition schedules make it increasingly difficult for players to compete at the highest level in both formats. The differences in position-specific competition requirements established in this thesis should be reflected in the training and nutrition programme, potentially resulting in conflicting or incompatible demands and objectives. In addition, in its current form, the schedule for international rugby sevens competition is unique in comparison with most other team sports. The IRB Sevens World Series is contested annually over a number of individual tournaments around the world. The men’s 2013/2014 IRB Sevens World Series consists of nine tournaments between October, 2013 and May, 2014. Consequently, the annual training programme must prepare players to be in peak physical condition at each individual tournament over an eight-month period. This objective conflicts with the preparatory and recovery needs of the more regular (typically weekly) contests during a rugby union season.

The annual training programme of rugby sevens players is typically implemented through a periodised approach structured around the competition season. The principles of overload, progression, specificity, and reversibility are applied to increase training loads and fitness in the pre-competition phase, maintain fitness during the competitive season, and allow recovery while minimising reversibility of fitness in the off-season [81]. To achieve parallel
improvements in the physical, physiological and technical factors that contribute to performance, rugby sevens players regularly undertake a mix of training methods including on-field training, resistance training and recovery [175]. A strategic approach to player development should consider the individual and combined objectives of these training methods, the temporal alignment of training sessions within a weekly micro-cycle, and potential interference of training adaptations [25,118].

It is important that a mixed training programme is designed recognising the short- and long-term physical effects on the athlete. In a single training session, an overload stimulus results in acute fatigue that manifests in a decrease in performance as a player’s ability to express their true physical capacity is temporarily suppressed. Training adaptations are the product of cumulative responses in the longer term that emerge after a period of recovery. Coaches applying a variety of training methods should consider the varying rates of recovery and adaptation for different physical qualities. Acknowledging differences in the time required for adaptations to occur will allow coaches to prescribe balanced programmes in which any decrement in physical capacity is less than the beneficial adaptation achieved. Structuring a programme in such a way should minimise the potential for interference or compromise in responses to training (Chapter Seven). For example, when attempting to simultaneously increase maximal power output and aerobic fitness, while allowing players to be in peak physical state leading into competition. Similarly, the rates of recovery and potential delay in observable training effects for different training methods also require consideration when structuring training and planning short- and long-term objectives. For instance, a rugby sevens training programme micro-cycle may include a single day incorporating three high-intensity, short-duration training sessions with three to four hours between each to condition players to the demands of tournament-style competition. Although this approach is likely to be beneficial to a player’s ability to perform repeated bouts of highly-demanding activity, coaches must consider the player’s acute response to each session and the potential for residual fatigue to influence performance in subsequent sessions.

The demands of international competition dictate successful players must simultaneously develop acceleration and speed, sport-specific endurance, strength and power qualities (Chapter Seven). The aim of the physical preparation programme is to develop both aerobic and anaerobic capacities so a player can sustain and reproduce high levels of power output during repeated bouts of work. Following the well-accepted principle of training specificity, on-field game-simulation training drills are often employed to enhance technical aspects of
performance, such as skill development and decision-making ability, under physical loads that replicate competition conditions. Given the observed differences in the physical load and intensity of domestic- and international-level competition, player selection and preparation should be specific to the level of competition at which a player is expected to compete (Chapter Six). Accordingly, game-simulation drills should mimic the duration and density of high-intensity efforts in competition.

The planned use of game-simulation drills, involving high volumes of maximal or near-maximal sprints, reactive agility and ball movements, at key stages of a rugby sevens team’s preparation can be a valuable method of conditioning players to the intensity of competition. Observations of contemporary training practices suggest international-level players’ development programme may be improved to more effectively use the limited preparation time available (Chapter Nine). By increasing the intensity and associated physiological load of game-simulation drills the specificity of training can be enhanced. In turn, coaches may reduce the overall volume of training for an equivalent load on players, thereby increasing training efficiency and lowering the risk of detrimental effects associated with high training volumes, such as injury [41,100], immunosuppression [113], and reduced performance. Naturally, the volume of high-intensity training requires careful consideration and planning, especially in regard to subsequent requirements for recovery between sessions to avoid non-functional overreaching and overtraining [174,188].

Effective testing and monitoring systems are a vital component of player development and physical preparation programmes [81]. Routine monitoring of training provides important feedback on players’ short-term responses to training and informs training prescription. During on-field training sessions, both the internal and external load on players should be assessed (Chapter Nine). In a rugby sevens context, internal load is typically measured using objective tools such as heart rate monitoring or more practical techniques such as subjective player ratings of perceived exertion [94]. External load is typically quantified using micro-technology, such as GPS devices. Several training drills or sessions must be monitored to account for the session-to-session variability when assessing changes or differences in measures of internal and external load within or between players. Averaging activity profile and physiological load measures over multiple sessions reduces the within-player variability to a value comparable with the smallest important change (a signal-to-noise ratio of ~1.0) (Chapter Nine). The number of repeated observations required to confidently quantify trivial
or small changes between sessions is dependent upon the signal-to-noise ratio of the metric used.

Regular evaluation of the physical and anthropometric attributes of players is useful in ensuring the appropriate adaptations to training and dietary interventions are being achieved. An array of tests assessing physical attributes and capacities, including physique and body composition, speed, power, strength, and endurance, may be administered in isolation or combination (Chapter Seven). By serially testing players throughout the periodised plan, a profile of strengths and weaknesses for each player can be used to individually customise the development programme and update training objectives. Testing players in the field provides a time- and cost-effective alternative to laboratory-based testing (Chapter Seven). For instance, the very large correlation \( r = 0.89 \) between the distance covered in the Yo-Yo IR1 test and a player’s running velocity at \( \dot{V}O_{2\text{max}} \) indicates the field-based measure can be used to assess players and set velocity thresholds for training and competition monitoring.

**Conclusion**

To my knowledge, at the commencement of this research programme only four full-text scientific articles investigating rugby sevens were published. This thesis has made a substantial contribution to our understanding of rugby sevens and requirements for player preparation. Each of the research studies contained in this thesis address an important factor relating to rugby sevens performance. Chapter Three to Chapter Six defined the technical, tactical, and physical demands of competition. Chapter Seven and Chapter Eight characterised the physique, physiological and performance qualities of international-level players. Finally, Chapter Nine assessed the specificity of on-field sport-specific training drills to refine the physical qualities of players. Clearly, the sport of rugby sevens has unique requirements that necessitate the development of a sport-specific framework for the technical and physical development of players. The practical outcomes of this thesis should have long-term implications for national coaching education and the direction of sport-specific talent identification and development systems in this rapidly evolving sport.
Chapter Eleven – Research Outcomes

The major findings of the research studies presented in this thesis contribute to and extend the existing body of knowledge with reference to rugby sevens. The research programme had eleven specific aims. These aims and the key research outcomes are detailed below.

Research Aims and Key Outcomes

Competition Analysis

1. Identify key performance indicators related to successful rugby sevens performance.

Analyses of match statistics collected from large representative samples of international matches generated reference values for common team performance indicators. Typical differences in performance indicator values between teams and variability between matches, tournaments and World Series competitions for a single team inform both short-term tactics and long-term strategies in rugby sevens.

2. Develop models for rugby sevens match performance prediction using team performance indicators.

Ruck and maul retention, possession time, the number of scrums and scrum possessions retained, the number of line-outs and line-out possessions retained, and kicks are positively related to the number of points scored by a team and the likelihood of winning a close match. Conversely, rucks and mauls per min of possession, turnovers conceded and turnovers conceded per min possession, opposition possession time, rucks and mauls, rucks and mauls retained, penalties and free kicks conceded, passes per min of possession are negatively related to scoring points and probability of winning. Higher-scoring and more-successful rugby sevens teams tend to control possession of the ball and play a patient, disciplined and evasive style of game.

3. Identify the relationship between team performance indicators and international rugby sevens tournament outcomes.

In an international rugby sevens tournament, more entries into the opposition’s 22-m zone per match, tries per entry into the opposition’s 22-m zone, tackles per match, passes per match, rucks per match and a higher percentage of tackle completion are associated with a better
ranking relative to other teams. Conversely, more passes per try, rucks per try, kicks per try, errors per match, surrendered possessions per match, and missed tackles per match are related to a worse ranking. The most successful teams are those that maintain ball possession by reducing errors and turnovers, are efficient in converting possession into tries, and have effective defensive structures resulting in a high rate of tackle completion.

4. *Identify specific technical and tactical factors (patterns of play) associated with success in international rugby sevens.*

Over an entire IRB Sevens World Series, more tries scored, penalties and free kicks conceded, and a higher percentage of own rucks won, percentage of opposition rucks won, and percentage of line-out possessions retained are related to a better ranking than other teams. Conversely, more tries conceded and a higher percentage of contestable restarts and percentage of tries conceded with no rucks than other teams are related to a poorer ranking.

5. *Quantify the differences in movement patterns between international and domestic rugby sevens tournaments.*

The gross relative movement demands of rugby sevens are ~20 to 45% greater and relative high velocity running demands more than double those of rugby union. International rugby sevens matches are more physically demanding than domestic-level matches owing to the greater distance covered at high velocities and higher frequency of changes in velocity. Distance covered in total and at ≥3.5 m·s⁻¹, maximal velocity, and the frequency of accelerations and decelerations are lower in forwards during international matches compared with backs. However, there are no clear positional group differences in physiological load during matches.

6. *Quantify changes in movement patterns within and between rugby sevens matches.*

The relative distance covered by players at velocities >2 m·s⁻¹ and frequency of changes in velocity is reduced from the first to second half of a match. There are small differences in players’ movements at <5 m·s⁻¹ and a small reduction in the number of moderate accelerations from the first to last match of a tournament.

7. *Assess the movement patterns of late-match substitute players in rugby sevens matches.*
Late-match substitute players have greater work-rates in the second half of matches than players contesting the full match.

**Player Selection and Development**

8. *Profile the physiological, anthropometric and performance characteristics of national-level rugby sevens players, and compare these results with previously published values for rugby union players.*

Rugby sevens players require highly-developed speed, power, and endurance qualities to meet the demands of competition. Rugby sevens players have anthropometric characteristics similar to those of backs in international rugby union, and acceleration and speed, lower-body muscular power and relative maximal aerobic power similar to, or exceeding, those of professional rugby union players.

9. *Quantify the relationships between anthropometric, physiological and performance test results in national-level rugby sevens players.*

Correlations between anthropometric, performance, and physiological measures emphasise the importance of physique and body composition in rugby sevens players, and highlight the need for players to develop speed and endurance without compromising other qualities pertinent to performance. Associations between laboratory- and field-based tests suggest field-based testing can provide a more practical method for assessing physical performance potential.

10. *Quantify and compare the distribution of fat, non-osseous lean and bone mineral mass in international rugby union and rugby sevens players.*

While forwards have a greater quantity of fat, lean and bone mass than backs in both rugby union and rugby sevens, the magnitude of difference between the positional groups is greater in rugby union players. When regional tissue mass is expressed as a proportion of total regional mass, positional group differences become predominantly unclear in rugby sevens players, but persist in rugby union players.

Competing at the international level in either rugby union or rugby sevens characterises the distribution of fat and non-osseous lean mass to a greater extent than a player’s positional group. However, the distribution of bone mineral mass is associated more with a player’s position than the rugby format in which they compete.
Specificity of Training

11. Examine the positional group-specific specificity of contemporary rugby sevens training practices in relation to the demands of competition.

Contemporary skill-refining and game-simulation drills of rugby sevens players at the national level generally do not replicate the physical and physiological demands of international competition for backs or forwards.

Limitations

Although the findings of this thesis have important implications for player development in the sport of rugby sevens, the following limitations are acknowledged.

- Match statistics analysed to model the relationship of team performance indicators with points scoring during matches, likelihood of winning, and final ranking in tournaments and over the IRB Sevens World Series were limited to those collected by the IRB and publicly accessible on the tournament website. The analysis of different match statistics should provide further insight into technical and tactical performance indicators related to successful outcomes in international rugby sevens. Despite this limitation, the analyses of the current match statistics described in the thesis were warranted as these official data are routinely collected by the sport’s governing body and available to all teams competing in the IRB Sevens World Series. It is therefore likely these data are used by coaches in planning their team’s preparation for competition.

- This thesis profiled the anthropometric, physiological, and performance characteristics of international-level Rugby Sevens players. The cohort of rugby sevens players investigated represented the national squad players of one country. As there are only a limited number of players in each national squad, the sample size available for investigation was limited to the number of available players free from injury or illness. A sample of this size does not permit normative values representative of all international-level rugby sevens players competing around the world to be derived. However, increasing the sample size by recruiting players competing at lower levels of the sport would have further limited the ability to apply findings to the target population of international-level players.
• Given logistical issues when studying players from national rugby union and rugby sevens squads during preparation for international competition, it was not possible to perform all DXA measurements using a single scanner. The use of a single DXA scanner to measure all players in both national squads would have permitted direct comparisons of the absolute and relative quantity of regional tissue mass of players in each squad.

Practical Applications
The findings of this thesis may be applied by coaches, support staff and players to better understand the nature of the game, the factors contributing to successful performances, the physical and physiological attributes of players, and training interventions to effectively prepare players for competition.

Competition Analysis
• Reference values for performance indicators derived during individual matches, full tournaments, or over the entire IRB Sevens World Series may be applied to evaluate team performances, establish match objectives and plan training programmes that improve a team’s probability of success in international competition.

• Team tactics that increase the amount of points scored and likelihood of winning should be based on strategies that promote greater ball possession, minimise rucks and mauls, turnovers, penalties and free kicks, and limit passes.

• Technical preparation for international competition should give attention to offence and defence. Successful teams in international rugby sevens tournaments maintain ball possession by reducing errors and turnovers, are efficient in converting possession into tries, and have effective defensive structures resulting in a high rate of tackle completion.

• To improve a team’s ranking in the IRB Sevens World Series, tactics should be based on scoring more and conceding fewer tries by maximising ball retention in line-outs and the breakdown, turning the ball over more frequently in opposition rucks, and pressuring the opposition in their territory by kicking fewer contestable restarts.
• Small reductions in player work-rate can be expected between the first and second half of a rugby sevens match. Tactical player substitutions in the latter stages of a match may be used to maintain or mitigate decrements in team work-rate.

• Movement pattern variables should be reported per min of activity and on an individual basis to account for differences in match time and between-player differences.

**Player Selection and Development**

• Physical preparation programmes of international rugby sevens players should aim to achieve concomitantly well-developed speed, power, and endurance qualities relative to rugby union players. Although these characteristics may be developed concurrently or in isolation depending on the individualised periodised training programme, the development of one aspect of fitness should not compromise another component of fitness relevant to performance.

• The periodised physical preparation programme of rugby sevens players should be based on an individual’s playing position and fitness profile. A regular testing regime will inform both team and individual player requirements.

• Rugby sevens players are likely to require superior endurance qualities to rugby union players to tolerate the higher running demands. Aerobic and anaerobic capacity should be prioritised within the physical preparation programme of rugby sevens players.

• To optimise physical preparation of players, training should be specific to the domestic or international competition level in which they are competing.

• Relatively uniform physical and performance standards should be developed for rugby sevens players, given the small between-player differences compared with rugby union players.

• Regular physiological and anthropometric assessments are recommended to monitor players’ physical development and progression. Simple field-based measures, such as the Yo-Yo IR1, may be employed to assess training adaptations and prescribe velocity thresholds for performance monitoring in place of time-consuming and expensive laboratory-based tests. A structured testing regimen conducted at various phases of
the season (e.g., off-season, preseason, midseason) will assist in planning periodised training programmes and evaluating their effectiveness.

- Increasing the body mass of international rugby players is likely to offer a competitive advantage. Physical preparation and dietary programmes should be designed to achieve a player’s optimal body mass considering their positional requirements. Achieving the ideal ratio of fat and lean mass in each anatomical region will contribute to optimal physical performance. The most effective absolute and relative tissue masses will vary between rugby formats, positions, and individuals. The advantage of a higher body mass in international rugby union forwards, even by an increase in absolute fat mass and at the expense of lower proportional non-osseous lean mass, appears greater than any potential detriment to speed and work capacity.

- Increasing the proportional mass in the upper body of rugby players, particularly through development of lean tissue in the arms, is likely to improve performance by assisting in many rugby-specific skills. Hypertrophy and strength training programmes should be designed to achieve this outcome.

**Specificity of Training**

- Although it may be undesirable for technically-focused drills to reproduce the physical loads of competition, game-simulation drills should reflect match demands to adequately prepare players for competition. Coaches could improve the management of their players’ training load and enhance training efficiency by increasing intensity and specificity and reducing the duration of sessions.

- There is a need for position-specific training approaches in rugby sevens, given substantial differences in activity profiles between backs and forwards during competition.

- Coaches should consider the influence of interruptions in training activity for instruction and feedback on the movement patterns and physiological load imposed on players. Monitoring the activity profile and physiological load of training activities should ensure training drills optimally prepare players for the demands of competition. Heart rate monitoring provides a useful index of a player’s internal response to training stimuli to ensure the appropriate adaptations are achieved, while
time-motion analyses using GPS devices provide an objective external measure of the work performed by a player.

- To longitudinally track an individual player or assess an intervention with a repeated-measures design using realistic sample sizes, several matches or training sessions should be monitored and averaged to reduce the within-player variability of movement patterns and physiological load measures.

**Directions for Future Research**

Continued progression in the immature and emerging international sport of rugby sevens means there is also a growing need for scientific research in performance analysis and player development specific to rugby sevens. Several directions for future research emerge from this thesis.

**Competition Analysis**

- Subsequent research should examine additional performance indicators not routinely collected by the IRB that may offer insight into other aspects of individual and team performance, such as indicators of defensive systems employed, tackle technique, and methods for contesting the ruck. Furthermore, analysis of the effects of situational variables, including the quality of opposition, environmental conditions, and match status, on a team’s technical performance and tactical decisions should further inform the preparation of teams for competition.

- Investigation of movement patterns of rugby sevens players during matches identified players may be pacing their activity, potentially to mitigate fatigue later in the match. Pacing and self-regulation of activity in rugby players will influence the prescription of training programmes and strategic rotation of players in tournaments. Future research could identify factors related to the development of fatigue and possible self-regulation of activity.

- Studies with a large sample of teams are required to identify individual positional differences in movement patterns in rugby sevens competition and potential distinctions between successful and unsuccessful teams. Similarly, investigations of large samples of international-level players could identify the technical and skill requirements during competition specific to individual positions. The findings of
studies in these areas should inform training prescription and player development strategies.

**Player Selection and Development**

- Strength and power are important qualities associated with success in rugby union. Collection of strength and power data would provide a more comprehensive description of the characteristics of elite-level rugby sevens players and permit comparisons between rugby sevens and rugby union players.

- Assessments of rugby sevens players competing at different levels of competition (e.g., local, national and international) is needed to confirm relationships between anthropometric, physiological, and performance characteristics and playing level.

- The typical (within-season) changes in anthropometric, physiological and performance characteristics of rugby sevens players over the course of an international season are unclear and require examination.

- The assessment of a large sample of international-level players will quantify physical characteristics and movement patterns during competition associated with different playing styles, selection policies, and ethnicities. The characteristics of players and/or movement patterns during matches may be related to whether a team typically adopts a direct or evasive style of play, the selection of younger or older, more physically mature and experienced players, or a player’s ethnicity (e.g., European, Melanesian, Polynesian).

- Research is required to identify the position-specific body composition and physique traits more likely to positively influence locomotion and performance measures, such as power output, running velocity, and scrummaging force.

- The interaction of biological (e.g., ethnicity, hormonal profile) and environmental factors (e.g., training, diet) that influence adipose, osseous, and non-osseous lean tissue distribution in rugby players requires further investigation. Knowledge of the factors affecting tissue distribution may assist in developing targeted dietary and physical preparation programmes for top-level players.

- The technical development of players could be objectively assessed through the design of empirically-validated match-related skills tests. The development of rugby-
specific skills tests would allow the technical proficiency of players to be monitored over time, as well as enable the comparison of players competing at different playing levels. Objective tests may also be applied to evaluate the effect of training interventions or fatigue on skill performance.

- The findings of this thesis may be progressed through an investigation of the relationships of a player’s physical development and physiological capacities with their activities and movement patterns during competition. Quantifying these associations could lead to the ability to predict or account for a degree of the variability in match activities through periodic physical testing of players. The ability to detect changes in fitness characteristics related to match performance is fundamentally important in governing training plans. Relating the results of physical tests with match activities, such as the volume of high-speed running; the number of match involvements; or the temporal changes in a player’s work-rate, would also describe the construct (convergent) validity of the tests to rugby sevens performance.

**Specificity of Training**

- Intervention studies are needed to quantify the effects of manipulating various training drill parameters on players’ physical and physiological responses and long-term adaptations. Understanding the effects of modifying training drill parameters, such as work-to-rest ratios, playing area dimensions, number of players, and rule changes, will assist in designing programmes that enhance the specificity of training.

- Research is required to quantify the specificity of the technical and tactical components of contemporary rugby sevens training practices and examine strategies that maximise skill learning. Investigating the optimal balance and sequencing of instructional skills training and match-specific drills, either in isolation or combination, would inform training programme design.

**Summary**

The series of progressive studies presented in this thesis have documented the technical and tactical elements associated with success in international rugby sevens matches, tournaments and the IRB Sevens World Series, quantified the physical and physiological requirements of competition, outlined the characteristics of international-level players and compared them with professional rugby union players, and examined the specificity of training activities
relative to competition. The outcomes of these investigations may be applied by coaches and support staff to monitor key measures of performance, prescribe evidence-based programmes, and develop the physical qualities and technical abilities of international-level players. Collectively, the information presented in this thesis assists in understanding the current nature of the emerging sport of rugby sevens and the factors associated with successful performance at the international level.
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Appendix A – Performance Nutrition Guidelines for International Rugby Sevens Tournaments


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**Abstract**

Rugby sevens is an abbreviated version of rugby union, played by teams of seven players over 7-min halves. International competitions are usually played in a tournament format. While shorter in duration, the movement demands of rugby sevens per min of match time are greater than rugby union, resulting in an accentuated load on players. This load can be repeated up to six times over a typical 2- or 3-day competition period. The potential cumulative effect of inadequate carbohydrate, protein and/or fluid intake over the course of a tournament is the greatest nutrition-related concern for players. Nutritional strategies prior to and during competition are suggested to replenish substrate stores, maintain fluid balance and promote recovery between matches. The use of ergogenic aids known to enhance intermittent, high-intensity activity and/or the execution of motor skills may be advantageous to rugby sevens performance and is discussed. This review provides a best-practice model of nutritional support for international rugby sevens competition based on our current understanding of the sport combined with pragmatic guidelines and considerations for the practitioner.

**Key words:** rugby union, competition, physiological demands, supplements, nutritional strategies, recovery
Appendix A – Performance Nutrition Guidelines for International Rugby Sevens Tournaments

Introduction

Rugby sevens is an abbreviated version of rugby union, played by teams of seven players over 7-min halves. A rugby sevens team is composed of three forwards, four backs and five replacements/substitutes. Given the importance of speed and agility in rugby sevens (Higham, Pyne, Anson, & Eddy, 2013; van Rooyen, Lombard, & Noakes, 2008), teams usually consist of mobile players that may compete as backs or loose forwards in 15-player rugby union. Rugby sevens has traditionally been utilised as part of the development pathway for younger players to progress to professional and international rugby union. However, given the burgeoning international popularity of rugby sevens and the differences in tactics, skills and physical demands between rugby union and rugby sevens, players are increasingly specialising in one of the two formats (Fuller, Taylor, & Molloy, 2010; Higham et al., 2013).

International men’s rugby sevens has been contested in the annual International Rugby Board (IRB) Sevens World Series since 1999. In 2012, the corresponding IRB Women’s Sevens World Series was introduced. The Rugby World Cup Sevens tournament has also been contested every four years since its inception in 1993. The global profile and participation rates of rugby sevens are likely to increase following the introduction of men’s and women’s competition at the 2016 Olympic Games. The sport’s Olympic debut compliments other multi-sport events where rugby sevens is currently played, such as the Commonwealth Games, Asian Games, Pacific Games, Pan American Games and World Games.

After considering players’ typical training patterns and physique characteristics, this review will focus on the physiological demands of competition and subsequent nutritional strategies that promote optimal performance in an international rugby sevens tournament. While the potential challenges faced by players training for and competing in both rugby union and rugby sevens are highlighted, it is beyond the scope of this review to detail energy and nutrient requirements for such players.

Due to limited literature detailing the physique characteristics of female players and physiological demands of women’s rugby sevens competition (Suarez-Arrones, Nuñez, Portillo, & Mendez-Villanueva, 2012), the guidelines presented in this review have been developed based primarily on research describing the demands of international men’s competition. Although it is necessary to consider sex-specific physique traits and training patterns, the nutrition guidelines and strategies for international competition may be equally
applicable to both male and female athletes, especially given they are presented relative to body mass.

**Typical Training Patterns**

Although there is increasing specialisation and professionalism in international rugby sevens, many players concurrently compete in rugby sevens and rugby union. Training for both rugby union and rugby sevens introduces many challenges including potentially competing demands, disparity in training objectives, and differences in the timing of competitive seasons (Higham et al., 2013). Players typically complete a periodised training programme combining rugby union training with additional sevens-specific conditioning. Sevens-specific sessions aim to develop speed, agility, and aerobic and anaerobic endurance. Strength and power characteristics are trained within a resistance-training programme periodised throughout the year. Most days of the week players will complete one to three sessions per day of 45–90 min duration, including on-field sessions as well as gym-based resistance training. Depending on training objectives, players’ running volume may range from 2–6.5 km per session completed at ~60–90 m·min⁻¹ (D.G. Higham, unpublished observations). While the gross movement intensity per min of training is similar to that reported for a 15-player rugby union match (Cahill, Lamb, Worsfold, Headey, & Murray, 2013; Cunniffe, Proctor, Baker, & Davies, 2009), work-to-rest ratios within training sessions are highly variable and physical contact demands are typically lower (Higham, Pyne, Anson, Hopkins, & Eddy, in press).

The greater volume and intensity of rugby sevens training compared with typical rugby union training practices increase the relative need for daily energy and macronutrient intake for recovery between sessions and maintenance of muscle mass.

**Competition**

In contrast to the traditional league-style format of rugby union competition where a maximum of two matches are usually played in any 7-day period, international rugby sevens competitions are typically played in a tournament format. The pre-eminent men’s rugby sevens competition is the IRB Sevens World Series, which comprises nine tournaments played around the world. Each tournament is contested by either 12 or 16 teams over a 2- or 3-day schedule. Teams play three matches in the pool stage on the first, or first and second day, then, depending on results, up to three matches during the knockout stages on the final day. Typical tournament scheduling includes periods of three to four hours between matches on the same day.
Unlike most team sports where nutrition support for competition occurs around a single match, rugby sevens players must consider eating and drinking around a 2- or 3-day multi-match tournament. Nutritional strategies that optimise muscle glycogen and fluid status prior to a tournament and promote rapid recovery following each match need to be utilised. Practical issues such as gastrointestinal comfort require consideration.

**Movement Patterns and Physiological Demands**

Although the duration of a rugby sevens match is considerably shorter than the 80 min of a rugby union match, relative to match time, male rugby sevens players cover ~20–45% greater distance (Higham, Pyne, Anson, & Eddy, 2012; Suarez-Arrones, Nuñez, Portillo, & Mendez-Villanueva, 2012). During a full match, rugby sevens players cover ~1400–2000 m at a mean intensity of 96–120 m·min$^{-1}$ (Higham et al., 2012; Higham, Pyne, Anson, Hopkins, et al., in press). Furthermore, rugby sevens players spend a higher proportion of the match running at high velocity (Suarez-Arrones et al., 2012) and cover more than double the distance at high velocity per min of match time than rugby union players (Higham et al., 2012). Although no published data currently exist comparing the intensity of tackles, scrums, rucks and mauls between rugby sevens and rugby union, it is likely the contact demands of rugby sevens are lower than rugby union. Nevertheless, the greater relative running volume and intensity observed in rugby sevens competition suggest the physiological demands of match-play are accentuated and that rugby sevens elicits a high physical load compared with rugby union competition (Higham et al., 2012; Rienzi, Reilly, & Malkin, 1999; Takahashi et al., 2007). Depending on player substitutions and rotations, this load can be repeated on two more occasions during the pool stage and again up to three times on the final day of competition. Although no published information currently exists, the repeated physical load on players is likely to result in disturbances to metabolic homeostasis and other central and peripheral factors of fatigue.

The degree of muscle damage experienced during exercise is related to both the intensity and duration of activity, with intensity having the greatest effect (Tiidus & Ianuzzo, 1983). Intermittent high-intensity running, typical of rugby sevens matches, results in a significant increase in muscle damage and soreness, particularly from the eccentric-loading phase of muscle contraction (Howatson & Milak, 2009; Thompson, Nicholas, & Williams, 1999). Despite specific training to condition players for these demands, players typically perform in excess of 40 accelerations ($\geq$2 m·s$^{-2}$) and decelerations ($\leq$-2 m·s$^{-2}$) in a full rugby sevens match (Higham et al., 2012). Although fewer rucks and mauls are formed and tackles made
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(Hughes & Jones, 2005) in rugby sevens than rugby union (Quarrie, Hopkins, Anthony, & Gill, 2013), rugby sevens competition is also characterised by frequent heavy-load collisions. Muscle damage is related to repeated, direct muscle trauma from impacts with other players and with the ground (Smart, Gill, Beaven, Cook, & Blazevich, 2008; Takarada, 2003). The observed rise in a marker of muscle damage in rugby sevens players after only a short exposure to match time (Takahashi et al., 2007) is an important consideration for coaches and support staff, especially as players may be required to compete in up to six matches in 2 days. Given muscle damage results in an increased metabolic cost during exercise and at rest (Tee, Bosch, & Lambert, 2007) and a reduction in muscle strength (Clarkson, Nosaka, & Braun, 1992), the implementation of recovery strategies including nutritional interventions (Baty et al., 2007) should be prioritised during rugby sevens tournaments. The physical and physiological load of rugby sevens, as well as the demanding travel schedule, have nutritional implications that require consideration to promote optimal performance during international tournaments.

Physique Characteristics

Despite an increase in the height and mass of rugby sevens players over the past 10 years, on average, male international rugby sevens backs are ~2 cm shorter and ~6 kg lighter than international rugby union backs, whereas forwards are ~1 cm shorter and ~13 kg lighter than their 15-a-side counterparts (Fuller et al., 2010). Furthermore, rugby sevens players are often leaner than professional rugby union players (Higham et al., 2013). Differences in physique between rugby sevens backs and forwards are less pronounced than positional differences of rugby union players, due to the smaller differences in movement patterns and increased need for mobility in all rugby sevens positions (Higham, Pyne, Anson, Dziedzic, & Slater, in press). Differences in physical attributes of rugby sevens and rugby union players reflect the higher running demands (Higham et al., 2012; Suarez-Arrones et al., 2012) and lower demands for physical confrontation in rugby sevens (Higham, Pyne, Anson, Dziedzic, et al., in press). Although a lighter body mass may be beneficial for performing frequent sprints, accelerating, decelerating, and changing direction when running, a higher body mass can increase a player’s momentum and be advantageous during contests for the ball.

Rugby sevens players aim to achieve an ideal body mass by developing a proportionally high muscle mass that assists in force production required for accelerating, sprinting, effecting and breaking tackles, and during rucks and mauls. Players simultaneously attempt to limit fat
mass which can compromise their power-to-weight ratio, metabolic efficiency (Withers, Craig, Bourdon, & Norton, 1987) and thermoregulation (Selkirk & McLellan, 2001). The transition of players between rugby union and rugby sevens may result in conflicting physique requirements and subsequent nutritional strategies.

Nutritional Strategies to Promote Optimal Performance

To our knowledge, there is no published data on the energy demands of rugby sevens. The relationship between heart rate and oxygen consumption has been used to estimate mean energy expenditure as 3.8–4.2 and 3.3–4.1 MJ in ~40 min of rugby league (Coutts, Reaburn, & Abt, 2003) and rugby union (Cunniffe et al., 2009), respectively. Including a warm-up, a single rugby sevens match is usually 30–35 min duration. Given the differences in duration and intensity, direct comparisons to a rugby sevens match are not possible. Nevertheless, when combined with the requirements needed to maintain lean mass (Oshima et al., 2011), the accumulated energy cost over a day in which three matches are played is likely to be considerable. The inconvenience of feeding around multiple, high-intensity matches intuitively suggests proactive nutritional strategies prior to the first match of each day, and aggressive eating and drinking plans after each match will, in addition to meeting acute recovery requirements, contribute to overall daily energy and macronutrient needs during a 2- or 3-day tournament. Anecdotally, some players report difficulty maintaining body mass while touring and competing. This experience emphasises the importance of adequate daily energy intake, particularly when two tournaments are played within a 10-day period.

The amount of high-intensity running performed by an athlete in multiple-sprint sports is influenced by pre-exercise muscle glycogen concentration (Balsom, Wood, Olsson, & Ekblom, 1999). Dietary composition can also affect short-duration (2–7 min), high-intensity exercise performance. In particular, low carbohydrate intake for 3–4 days prior to exercise will limit carbohydrate availability and likely compromise exercise capacity (Maughan, Greenhaff, et al., 1997). Additionally, restoration of muscle glycogen concentrations is higher when a carbohydrate-enriched diet (~8.4 g carbohydrate per kilogram body mass per day (g CHO-kg\(^{-1}\) BM\(^{-1}\)) is consumed before competitive team sports (Akermark, Jacobs, Rasmusson, & Karlsson, 1996). It follows that rugby sevens players should employ a similar protocol, incorporating a proportionally higher carbohydrate intake in the final days leading into an international tournament. Consumption of 5–8 g CHO-kg\(^{-1}\) BM\(^{-1}\) in combination with the taper in training load over the final two days of preparation will help optimise
endogenous substrate stores (Burke et al., 1995). This is of particular importance given players must compete in multiple matches over a 48- or 72-hour period with as little as three hours recovery between matches.

Scheduling of matches is dependent on each tournament draw with the first match usually played between mid-morning and midday on each day of competition. This schedule allows players the opportunity to consume a substantial carbohydrate-rich meal ~3–4 hours and another snack 1–2 hours prior to the first match. This is in line with current recommendations for pre-event nutrition (Rodriguez, DiMarco, & Langley, 2009). In addition, the period prior to the first match of each day provides athletes with the chance to consume adequate fluid to ensure they are well hydrated.

Although played at a relatively high intensity, the brief work period allows for, and demands little emphasis on performance-related nutritional strategies during a single match, particularly if an appropriate pre-match meal or snack has restored muscle and liver glycogen levels. The opportunity to consume food or fluid during a rugby sevens match is largely restricted to a brief 2-min half-time interval. This short recess and the intensity at which a match is played limit a player’s ability to tolerate large gastrointestinal quantities. Players often consume between 200–600 mL of water and/or sports drink during the pre-match warm up and stoppages throughout a match (Dziedzic, 2011), most likely for sensory benefits.

Resynthesis of muscle glycogen stores and repair of muscle tissue damage should be prioritised following each match, as this is a period not only for recovery but also preparation for subsequent matches. Since both anaerobic and aerobic energy pathways contribute to rugby performance (Duthie, Pyne, & Hooper, 2003), considerable carbohydrate utilisation is expected during competition. While the duration of a single rugby sevens match will not deplete muscle glycogen stores, partial glycogen depletion is likely, given degradation increases exponentially with exercise intensity (Maughan, Greenhaff, et al., 1997). Since muscle damage due to direct impact or eccentric loading interferes with glycogen storage (Costill et al., 1990), it follows that aggressive carbohydrate feeding during recovery is important to the rugby sevens player. To maximise muscle glycogen resynthesis, players should ingest 1–1.5 g CHO·kg\(^{-1}\) BM within 30 min after each match (Kerksick et al., 2008; Rodriguez et al., 2009). The form of carbohydrate is less important in providing a substrate for synthesis (Keizer, Kuipers, van Kranenburg, & Geurten, 1987). However, liquid forms are a practical and appealing way to meet rapid refuelling requirements following a match.
While difficult to quantify, the cognitive aspects of play significantly contribute to the outcome of a match (Roberts, Trewartha, Higgitt, El-Abd, & Stokes, 2008). In addition to the physiological requirements for carbohydrate feeding, the execution of skills and cognition required for decision making rely on the maintenance of blood-glucose levels (Karelis, Smith, Passe, & Péronnet, 2010). Furthermore, carbohydrate ingestion may play a role in attenuating central fatigue related to perception of effort and muscle fatigue (Karelis et al., 2010).

Exercise-induced muscle damage degrades protein structures and may lead to decrements in muscle function (Twist & Eston, 2005). In addition to potentially augmenting glycogen synthesis during recovery (Ivy et al., 2002; van Loon, Saris, Kruijshoop, & Wagenmakers, 2000), co-ingestion of protein is essential to repair muscle proteins for energy metabolism and force production (Rodriguez, Vislocky, & Gaine, 2007). Essential amino acids are available in the blood ~60 min after protein ingestion and lead to an increased mixed skeletal muscle fractional synthetic rate, inducing a positive whole-body net protein balance during recovery (Howarth, Moreau, Phillips, & Gibala, 2009). Ingestion of ~20 g of high biological value proteins elicits a maximal response of muscle fractional synthetic rate in the immediate recovery from resistance training (Moore et al., 2009). The ingestion of protein between two bouts of intense exercise separated by 4 hours has been shown to enhance muscle repair and reduce muscle soreness (Rowlands, Thorp, Rossler, Graham, & Rockell, 2007), potentially contributing to subsequent high-intensity performance capacity. Therefore it is reasonable to suggest players should consume similar quantities (20–25 g) of protein to optimise the repair of muscle tissue following the damage associated with each rugby sevens match, especially considering the shortened recovery period between matches and the relatively high lean mass of players.

An inability to adequately replace body water when training and competing on consecutive days has been reported in professional rugby league players (Meir & Murphy, 1998), which may lead to chronic hypohydration. During a domestic-level competition pool match and standard warm up played in mild environmental conditions (23–25 °C, 60–65% relative humidity), Australian rugby sevens players averaged a total sweat loss of ~1000 mL, resulting in a mean net fluid loss of ~1% BM (Dziedzic, 2011). Although it is difficult to anticipate sweat losses during international competition, it seems reasonable to speculate that sweat losses may be substantial since World Series tournaments exert a high physiological load on players and are typically played in hot and potentially humid environments. Fluid losses as low as 1% BM may affect thermoregulatory function during exercise in the heat.
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(Casa et al., 2010). Intermittent sprint performance is also adversely affected by a low to moderate (~2% BM) fluid deficit (Baker, Dougherty, Chow, & Kenney, 2007). The impairment of physical and/or mental performance may be amplified if players commence competition hypohydrated (Maughan & Shirreffs, 2007). Monitoring changes in pre- and post-match body mass followed by the consumption of 150% of sweat losses in fluid prior to the next match is recommended (Sawka et al., 2007). Fluid balance requires restoration in a timely manner, and may be augmented by consuming sodium-containing fluids and food to drive players’ thirst and increase voluntary intake, as well as enhance fluid retention (Shirreffs, Armstrong, & Cheuvront, 2004). It is important rehydration at the end of pool stage days occurs early in the recovery period, as drinking large volumes in the hours before sleep may lead to overnight interruptions and impact on sleep quality.

**Ergogenic Aids**

Although there is a dearth of literature on the use and effects of supplementation in rugby sevens, ergogenic aids known to enhance strength and power, intermittent, high-intensity activity, and the execution of motor skills or cognitive ability may be advantageous.

Supraphysiological supplementation of creatine improves a player’s work capacity within a training session and can positively influence changes in muscle protein accretion (Cooper, Naclerio, Allgrove, & Jimenez, 2012), augmenting training adaptations of muscle strength and power. The role of creatine in increasing the rate of creatine phosphate resynthesis during recovery between high-intensity bouts of exercise (Greenhaff, 2000) is also applicable to match performance, as supplementation enhances power output during short maximal sprints during intermittent exercise (Terjung et al., 2000). Additionally, creatine ingestion with a carbohydrate-rich diet can enhance post-exercise glycogen repletion (van Loon et al., 2004), which is beneficial when recovery time between matches is limited. The timing and dosage of creatine monohydrate loading must be considered when attempting to enhance rugby sevens match performance. Rapid-loading protocols have been associated with body water weight gain (Hultman, Soderlund, Timmons, Cederblad, & Greenhaff, 1996). Therefore, it is suggested players undertake a slow-loading protocol of 3 g·d\(^{-1}\) over 28 days or schedule an appropriate rapid-loading phase of 20 g·d\(^{-1}\) over five days, in attempt to avoid weight gain that may compromise their power-to-weight ratio before a tournament. Muscle creatine accumulation is likely to be enhanced when co-ingested with 75–100 g of carbohydrate (Green, Hultman, Macdonald, Sewell, & Greenhaff, 1996).
Caffeine ingestion in doses of 1–6 mg·kg⁻¹ BM influences processes in the central nervous system to reduce perception of fatigue, enhance central drive and improve muscle fibre recruitment (Magkos & Kavouras, 2005). An investigation of caffeine (4 mg·kg⁻¹ BM) administered in combination with carbohydrate 60 min prior to exercise concluded it was either the effect of caffeine alone or the interaction of carbohydrate and caffeine that resulted in improvements in a rugby-specific maximal-intensity test, a 15-m sprint and a motor skills task (Roberts et al., 2010). Similarly, caffeine ingestion (6 mg·kg⁻¹ BM) improved sprint times by 0.5–2.9% during a simulated rugby union-specific test and resulted in improved passing accuracy compared with a placebo (Stuart, Hopkins, Cook, & Cairns, 2005). In a randomised, double-blinded, placebo-controlled study, the ingestion of a caffeinated beverage (3 mg·kg⁻¹ BM) by members of the Spanish women’s rugby sevens team 60 min prior to exercise increased power output during a 15-s maximal jump test and increased total distance covered per min and distance covered per min at >3.33 m·s⁻¹ during a friendly international tournament compared with the placebo (Del Coso et al., 2013).

Although beneficial effects of caffeine on physical and skill activities required in an intermittent, high-intensity team sport have been observed when ingested 60 min prior to matches, rugby sevens players must make some considerations before use during competition. Given caffeine is slowly catabolised and has the potential to interfere with sleep and affect subsequent performance (Burke, 2008), players must consider the effects of repeated dosing of caffeine, particularly throughout the first day of play. Players considering the use of caffeine to enhance performance should trial doses of 1–3 mg·kg⁻¹ BM and monitor tolerance and side-effects during training or domestic tournaments. It would also be prudent to develop an individualised, strategic plan of caffeine use considering the timing of matches and importance of each outcome, avoiding doses greater than 6 mg·kg⁻¹ BM·d⁻¹.

Sodium bicarbonate ingestion can be beneficial for exercise lasting 1–5 min by increasing extracellular buffering capacity (McNaughton, Siegler, & Midgley, 2008). While ergogenic effects are observed in multiple bouts of high-intensity, short-duration exercise interspersed by short recovery intervals (Bishop, Edge, Davis, & Goodman, 2004), sodium bicarbonate supplementation in rugby sevens is limited by practical issues. Many players are unable to tolerate the ingestion of large doses based on recommendations relative to body size combined with the consumption of substantial volumes of fluid required to mitigate gastrointestinal distress prior to engaging in a high-intensity, contact sport. The adoption of a chronic-loading protocol may be most appropriate to reduce the risk of gastrointestinal upset.
In this case, split doses (totaling 0.5 g·kg\(^{-1}\)·d\(^{-1}\)) of bicarbonate are taken for 3–5 days and then ceased 12–24 hours prior to the first match (Burke & Pyne, 2007). Even so, tolerance should be trialled in training before use in competition. Emerging evidence that beta-alanine may elicit ergogenic effects (Artioli, Gualano, Smith, Stout, & Lancha, 2010) due to its role in increasing muscle carnosine content (Harris et al., 2006), a known intracellular buffer, could be explored as an alternative to sodium bicarbonate. However, the effects of beta-alanine supplementation on rugby sevens performance are currently unknown.

The use of liquid meal replacements and sports foods, such as carbohydrate and/or protein powders and sports bars, may be necessary for travel and to accommodate changes in typical between-meal snack choices and access. Sports drinks, specifically-formulated recovery beverages and electrolyte supplements may assist in meeting acute nutritional requirements before, during and after matches (Sawka et al., 2007).

**Practical Challenges and Guidelines**

The IRB Sevens World Series is contested in cities around the world, making travel a significant consideration for the rugby sevens player (for a review of travel nutrition see Reilly, Waterhouse, Burke, and Alonso, 2007). Acute issues around travel such as food availability and appropriateness in transit, attenuating the effects of jet lag (Samuels, 2012) and boosting players’ immunity (Schwellnus et al., 2012) should be considered, but are beyond the scope of this review. A constraint faced by players during international tournaments is the standard hotel catering arrangements which accommodate all competing teams. Access to suitable between-meal and pre- and post-training snacks to meet both acute and daily energy and nutrient requirements is a concern during the final days of preparation and while on tour for up to three weeks. Although the eating patterns and dietary composition of rugby sevens players have not been described, between-meal snacks in elite athletes in other sports account for 20–30% of typical daily energy intake (Burke et al., 2003; de Wijn & van Erp-Baart, 1980). Limited availability of snacks while touring may therefore contribute to a reduction in body mass. Timing and availability of appropriate food choices on match days must also be considered. Strategies to combat such issues include the organisation and management of travelling food supplies and player education. Investigating the range of food options and hours of operation of hotel and competition venue dining facilities will assist in providing appropriate meals and snacks prior to and during competition. Nutrition guidelines to optimise performance during a tournament are described in Table A-1. An outline of the key nutrition guidelines around a typical tournament schedule is presented in Figure A-1.
While aiming to achieve the nutrition targets that promote optimal performance, a flexible and individualised approach is necessary. Practical issues such as the players’ food preferences, psychological aspects of match-day nutrition, and gastrointestinal comfort will influence the pre-event nutrition strategies for individual players.
Table A-1. Practical nutrition guidelines to optimise performance during an international rugby sevens tournament.

<table>
<thead>
<tr>
<th>Goal</th>
<th>Guidelines</th>
<th>Practical considerations</th>
</tr>
</thead>
</table>
| 1. Optimise glycogen stores prior to tournament commencement | Increase carbohydrate availability by consuming 5–8 g·kg⁻¹BM·d⁻¹ for 1–2 days prior to tournament | • Choose carbohydrate-rich foods at each meal and snack, avoiding excessive high fibre sources  
• Make use of carbohydrate-containing fluids  
• Plan food intake around hotel catering (three daily meals) by having access to suitable between-meal, and pre- and post-training snacks |
| 2. Optimise hydration status prior to tournament commencement | • Urine specific gravity of upon-waking sample <1.020 on match day  
• Monitor daily body mass changes  
• Monitor pre- and post-training body mass changes | • Consume fluid at every meal and snack  
• Have access to a variety of fluids to encourage voluntary drinking  
• Replace 150% of sweat losses with fluid in the 2–4 h following training during final preparation days |
| 3. Maintain muscle glycogen stores and fluid status on match days | • Consume carbohydrate-rich pre-match meal 3–4 h, and snack 1–2 h prior to first match  
• Consume adequate fluid based on an individualised drinking plan | • Have access to familiar and suitable pre-match snacks in addition to hotel catering choices  
• Choose moderate-fibre foods, low in fat  
• Have access to a variety of fluids to encourage voluntary drinking |
| 4. Recover immediately to resynthesize muscle glycogen, repair muscle damage and replenish fluid stores after each match | • Consume 1–1.5 g CHO·kg⁻¹BM in combination with 20–25 g protein within 30 min after each match  
• Replace 150% of sweat losses with fluid prior to the next match | • Make use of sports foods such as liquid meal supplements, sports drinks, bars and gels  
• Inclusion of electrolyte supplements in fluids and/or salty snacks may be useful if large sweat losses occur |
| 5. Meet match-day energy requirements | • Consume a substantial meal and snack prior to first match and following final match, particularly on first day of competition  
• Meet acute recovery nutrition needs following each match (Goal 4)  
• Aim to consume small and frequent snacks throughout the remainder of the day | • Plan food intake around catering meal times and choices  
• Have access to appropriate snacks and sports foods to allow flexibility of food and fluid intake around hotel meal times  
• Plan appropriate strategies to manage issues such as reduced appetite and individual tolerance of food and fluid |
| 6. Make appropriate use of evidence-based ergogenic aids | • Creatine monohydrate  
○ Slow-loading protocol: 3 g·d⁻¹ over 28 days  
○ Rapid-loading protocol: 20 g·d⁻¹ (split doses 4 × 5 g) over 5 days  
• Caffeine  
○ 1–3 mg·kg⁻¹BM, 1 h prior to matches | • Creatine should be appropriately timed to avoid rapid-loading protocols in the lead up to tournaments  
• Creatine doses should be co-ingested with 75–100 g of carbohydrate  
• Strategic use of caffeine should be trialled and employed only after considering match schedules and side effects of repeated use during tournament days |
Figure A-1. Timeline of key nutrition guidelines for a typical tournament schedule. g CHO·g⁻¹·BM·d⁻¹ = grams of carbohydrate per kilogram of body mass per day.
Conclusion
The popularity and profile of rugby sevens has increased in recent decades, yet literature detailing the specific demands of the sport and the associated characteristics of players is only emerging. Current nutrition guidelines to optimise tournament performance have therefore been inferred from other athletic populations or situations with similar physiological stresses. The unique demands of rugby sevens warrant further investigation, particularly in relation to nutritional strategies likely to affect performance. Additionally, future research should aim to document players’ current nutrition practices during training and competition. This review provides a best-practice model of nutritional support for international rugby sevens competition based on our current understanding of the sport and its requirements combined with pragmatic guidelines and considerations for the practitioner.
References


Appendix A – Performance Nutrition Guidelines for International Rugby Sevens Tournaments


Appendix A – Performance Nutrition Guidelines for International Rugby Sevens Tournaments


Appendix B – Running Movement Patterns in Rugby Sevens Football

Higham, D.G. 1,2,3), Pyne, D.B. 1,2), Anson, J.M. 2), Eddy, A. 3)
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2) University of Canberra, Australia
3) Australian Rugby Union, Australia

Key words: GPS, motion analysis, accelerations

Introduction
Rugby sevens, an increasingly popular variant of rugby union, is played over two 7-min halves with seven players on each team. The physical demands of rugby sevens competition are not well understood. The aim of this study was to quantify the movement patterns of elite-level rugby sevens players during competition.

Methods
Movement patterns of 19 international-level male rugby sevens players were recorded using a Global Positioning System (GPS) device (Team Sport version 2.5, Catapult Innovations, Australia) recording at 5 Hz during 27 matches. A total of 174 match files were analyzed. Movement patterns were quantified based on distance covered in velocity zones (0 to 2, 2 to 3.5, 3.5 to 5, 5 to 6 and >6 m·s⁻¹) and number of moderate (2 to 4 m·s⁻²) and high (>4 m·s⁻²) accelerations and decelerations (-2 to -4 m·s⁻²; <-4 m·s⁻², respectively). Results are expressed per min of playing time to account for player substitutions.

Results and Discussion
Players spent a total of 10:48 ± 4:22 min:s (mean ± SD) on the field covering 120 ± 17 m·min⁻¹ and reaching a peak velocity of 8.3 ± 1.1 m·s⁻¹. Although most locomotor activity occurred at low velocity (35 ± 6% at 0 to 2 m·s⁻¹), a substantial proportion of distance was covered at high velocity (e.g., 10 ± 5% at >6 m·s⁻¹) (Table B-1). Total distance covered per min and distance

<table>
<thead>
<tr>
<th>Variable (per min)</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (m) at 0-2 m·s⁻¹</td>
<td>41.3 ± 6.2</td>
</tr>
<tr>
<td>Distance (m) at 2-3.5 m·s⁻¹</td>
<td>32.1 ± 7.4</td>
</tr>
<tr>
<td>Distance (m) at 3.5-5 m·s⁻¹</td>
<td>24.5 ± 6.6</td>
</tr>
<tr>
<td>Distance (m) at 5-6 m·s⁻¹</td>
<td>10.6 ± 4.6</td>
</tr>
<tr>
<td>Distance (m) at &gt;6 m·s⁻¹</td>
<td>11.8 ± 7.3</td>
</tr>
<tr>
<td>Moderate accelerations (#)</td>
<td>1.1 ± 0.5</td>
</tr>
<tr>
<td>High accelerations (#)</td>
<td>0.4 ± 0.3</td>
</tr>
<tr>
<td>Moderate decelerations (#)</td>
<td>1.3 ± 0.6</td>
</tr>
<tr>
<td>High decelerations (#)</td>
<td>0.3 ± 0.2</td>
</tr>
</tbody>
</table>
travelled at >5 m·s\(^{-1}\) per min were substantially greater (by ~45 and 135\%, respectively) in rugby sevens than in 15-player rugby union (1).

**Conclusion**

Rugby sevens is characterised by a high frequency of changes in velocity and repeated high velocity sprints. Game-specific training should include relatively high running volumes incorporating intermittent maximal or near-maximal sprint efforts.

**References**

Appendix C – What Physical and Performance Qualities Characterise Elite Rugby Sevens Players?

Higham, D.G.1,2,3; Pyne, D.B.1,2; Anson, J.M.2

1: Australian Institute of Sport (Canberra, Australia), 2: University of Canberra (Canberra, Australia), 3: Australian Rugby Union (Sydney, Australia)

Introduction

Rugby sevens is a format of rugby union that has increased in popularity in recent years and will be contested at the Olympic Games from 2016. Marked differences in the specific demands of competition between 15-player rugby union and rugby sevens suggest the characteristics of high-level players in each format may also differ (Higham et al., 2011). Although the characteristics of 15-a-side rugby union players have been well defined, little information exists on rugby sevens players. We profiled the anthropometric, physiological and performance qualities of elite-level rugby sevens players, and quantified relationships between these characteristics.

Methods

Eighteen male international rugby sevens players undertook anthropometric (body mass, height, sum of seven skinfolds, lean mass index), acceleration and speed (40-m sprint), muscular power (vertical jump), repeated-sprint ability (6 × 30-m sprint) and endurance (Yo-Yo intermittent recovery level 1 test and treadmill VO\(_{2\text{max}}\) testing. Associations between measurements were assessed by correlation analysis.

Results

Rugby sevens players had anthropometric characteristics (body mass 89.7 ± 7.6 kg, height 1.83 ± 0.06 m, sum of skinfolds 52.2 ± 11.5 mm; mean ± SD) similar to backs in international 15-player rugby union. Acceleration and speed (40-m sprint 5.11 ± 0.15 s), muscular power (vertical jump 66 ± 7 cm), and endurance (VO\(_{2\text{max}}\) 53.8 ± 3.4 mL·kg\(^{-1}\)·min\(^{-1}\)) qualities were similar to, or better than, professional 15-a-side players. Coefficients of variation ranged from 2.5 to 22%. Relative VO\(_{2\text{max}}\) was largely correlated with Yo-Yo distance (r = 0.60, 0.21 to 0.82; 90% confidence interval) and moderately correlated with 40-m sprint time (r = -0.46, -0.75 to -0.02) and repeated-sprint ability (r = -0.38, -0.72 to 0.09).
A very large correlation was observed between velocity at $\dot{\text{VO}}_{2\text{max}}$ and Yo-Yo distance ($r = 0.89$, 0.74 to 0.96).

**Discussion**

Our findings provide an important first step toward the development of physical performance standards for players training to compete at the international level. International rugby sevens players require highly-developed speed, power and endurance to tolerate the demands of competition. The small between-athlete variability of characteristics in rugby sevens players highlights the need for relatively uniform physical and performance standards in contrast with 15-a-side teams. Simple field-based measures may be employed to assess training adaptations and prescribe velocity thresholds for performance monitoring in place of time-consuming and expensive laboratory-based tests.

**References**

Appendix D – Comparison of Fitness Characteristics between Men’s and Women’s Rugby Sevens Players

David B. Pyne¹, Dean G. Higham¹, Anthea Clarke¹, John Mitchell², Anthony Eddy²

¹Australian Institute of Sport, Belconnen, Australia. ²Australian Rugby Union, St Leonards, Australia.

Both men’s and women’s rugby sevens have been added to the program for the 2016 Olympic Games in Rio de Janeiro, Brazil, but little is known about the comparative fitness requirements.

Purpose
To determine magnitudes of difference, and degree of variability, in standard anthropometric and fitness characteristics of national-level men and women rugby sevens players.

Methods
National sevens squad players (males n = 32, age 22 ± 3 y; height 1.82 ± 0.06 m; mass 90 ± 8 kg; females n = 32, age 25 ± 6 y, height 1.68 ± 0.06 m; mass 70 ± 9 kg; mean ± SD) age were tested during routine training camps. All testing was conducted indoors on a synthetic running track after instruction, warm-up and familiarization with each test protocol. Each player completed a 40-m maximal sprint test, standing vertical jump and the Yo-Yo Intermittent Recovery Level 1 (YoYo-IRL1) tests. Difference in mean scores between male and female players were expressed as a percentage, and variability as a ratio of the coefficients of variation (CV).

Results
Male players had ~40% more lean mass and 40% lower skinfolds than the women. Speed (40-m sprint time and maximal running velocity, \( v_{\text{max}} \)) was only ~10-20% faster for the men, while lower body power and momentum (mass × \( v_{\text{max}} \)) were 40-50% higher in men. The most marked difference was in endurance capacity (YoYo-IRL1 distance covered) where the men (2260 ± 270 m; mean ± SD) were ~two-fold better on the YoYo-IRL1 than women (990 ±
320 m; mean difference ± 90% confidence limits of 1234 ± 184 m). The women were more than twice as variable (ratio of CV <0.4) in endurance fitness than the men.

**Conclusion**

Women rugby sevens players should focus conditioning programs on power, size and endurance to improve these aspects of fitness.
Appendix E – Comparison of 5- And 10-Hz GPS Technology for Team Sport Analysis

David B. Pyne, Carl Petersen, Dean G. Higham, Matthew N. Cramer

*Australian Institute of Sport, Belconen, Australia*

Game and training analysis in team sports is increasingly reliant on application of smart sensor devices and wireless technology.

**Purpose**
To compare the reliability and validity of 5- and 10-Hz Global Positioning System (GPS) devices for quantifying distances of short sprints in team sport athletes.

**Methods**
Twenty trials of maximal effort short sprints over 10-, 20-, 30- and 40-m intervals using a MinimaxX GPS device (Team Sport version 4.0 10-Hz, Catapult, Melbourne, Australia) were evaluated against a criterion measure of electronic timing (Swift timing gates, Lismore, Australia; accurate to 0.01 s). Data were log-transformed before analysis to reduce the non-uniformity of error. Validity was quantified with the standard error of the estimate (SEE) and reliability estimated using the typical error expressed as a coefficient of variation. These estimates were then compared with previously established values for a 5-Hz device (Team Sport version 2.5) for 20-, 30- and 40-m intervals.

**Results**
The estimates of validity (standard error of the estimate ± 90% confidence limits) of the new 10-Hz device were: 10-m, 13.9 ± 5.1%; 20-m, 8.8 ± 3.2%; 30-m, 6.2 ± 2.3%; and 40-m, 5.0 ± 1.8%. The estimates of reliability (typical error ± 90% confidence limits) for the 10-Hz device were: 10-m, 11.7 ± 3.6%; 20-m, 6.9 ± 2.1%; 30-m, 4.7 ± 1.4%; and 40-m, 3.8 ± 1.1%. Comparable mean estimates for the older 5-Hz device over 20-40 m intervals ranged from 14-24% for validity, and 16-30% for reliability.

**Conclusions**
The reliability and validity of estimates for quantifying the distance covered in short sprints is markedly better using 10-Hz GPS technology.