

Improving the Physical Preparation and Development of Women's Rugby Sevens Players

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Thesis Abstract

With the introduction of rugby sevens to the Olympic Games schedule from 2016, the exposure and increased professionalisation of the sport has grown rapidly worldwide in both the men's and women's game. Substantial investment is being directed into rugby sevens to better characterise the game demands and training requirements for enhancing the preparation and management of players. However, most research in rugby sevens has examined male players only, and unique differences between sexes, including aspects of physiology, health, and contextual factors, may limit the translational efficacy of this information to the women's game. The purpose of this thesis was to evaluate strategies for improving the management of women's rugby sevens players' health and physical development, assessment of game and training demands, and prescription of training and talent identification processes. In total, this thesis contains six independent studies that address aspects of these strategies. The first study was a cross-sectional comparison of the game demands and physical profiles of male and female rugby sevens players at three levels of competition. The second and third studies assessed microtechnology use for rugby sevens through a laboratory-based protocol to develop a physiologically-defined high-intensity speed threshold for women, and evaluated the efficacy of automated collision detection technology. Studies four and five were observational studies comparing the neuromuscular fatigue, muscle damage and inflammation between State and National level players following a two-day women's rugby sevens tournament. Finally, study six, a clinical investigation, explored sex differences in iron levels across a competitive season in male and female elite-level rugby sevens players.

Assessment of game movements and physical profiles of rugby sevens players showed small to large differences between playing levels (junior, senior, and elite) for most metrics in female players. In contrast, minimal differences were apparent between playing levels for men. Correlational analysis showed that superior physical fitness (aerobic, speed, power) was beneficial ($r = 0.39 - 0.65$) for game performance in female players. Training can now be prescribed for players based on the typical movement patterns of current or aspirational levels of competition, with assessment of general athletic ability recommended for all female rugby sevens players and talent identification. A sex-specific physiologically-defined threshold for high-speed running was established for female players. The

commonly used threshold of $5 \text{ m}\cdot\text{s}^{-1}$ in men's rugby underestimated high-intensity running by up to 30% for female rugby sevens players, favouring those players who are typically sprinters. A mean physiologically-defined threshold of $3.5 \text{ m}\cdot\text{s}^{-1}$ was determined to be more appropriate for assessing high-intensity running by female players. If adopted, this metric, or reference value, offers coaching staff a more accurate understanding of the running movements and demands of training and competition on female players. Automatic detection of collision events using microtechnology was deemed not of an acceptable standard given poor recall (0.45 – 0.69) and precision (0.71 – 0.73) in rugby sevens. It appears the nature of collision events in rugby sevens is different to other rugby codes (primarily related to differences in speed and number of players involved) from which algorithms were originally developed. Moreover, consideration of differences in size, strength, tackle technique, or patterns of play is needed to develop female-specific rugby sevens algorithm.

Substantial muscle damage, inflammation and impaired perceptions of fatigue and soreness occurred following a two-day women's rugby sevens tournament. National level players completed moderate to largely greater game movements during the tournament (standardised effect size (ES) = 0.65 – 1.32), however, State level players exhibited a higher (ES = 0.73) physiological disturbance in the muscle damage marker creatine kinase (CK). High-speed running ($>5 \text{ m}\cdot\text{s}^{-1}$) and impacts $>10 \text{ g}$ -force had large to very large positive correlations ($r = 0.70 - 0.90$) with the change in CK concentration for both State and National level players. Meanwhile, the post-tournament neutrophil count was large to very largely correlated ($r = 0.57 - 0.89$) with the total game movements of players regardless of playing level. Training should focus on high-speed running movements and collisions to adequately prepare players for competition and limit physiological disturbances induced by competition. Recovery practices should be implemented based on the total game time or running distance that players complete. Monitoring players over a competitive season for the presence of iron deficiency indicated that up to 30% of an elite women's rugby sevens squad had low iron stores at each time-point (pre-, mid-, and end-season). While the effect of an oral contraceptive on the serum ferritin level of female players ($r = -0.29 \pm 0.59$) was unclear, players who competed in four or more tournaments throughout the season had ~50% lower ferritin concentration than those who competed in less than four, while age was largely positively correlated ($r = 0.66 \pm \sim 0.33$) with ferritin concentration. Haematological

testing is recommended every six months for female players, corresponding to pre-season and mid-season time points.

In summary, women's rugby sevens programs should benefit from regular assessment of physical fitness within and between seasons, using a women's specific threshold of $3.5 \text{ m}\cdot\text{s}^{-1}$ to assess high-intensity running, targeted recovery interventions during and after two-day tournaments, further refinement of automated technology to monitor impacts and collisions, and implementation of protocols to monitor and address iron status in female rugby sevens players.

Statement of Contribution by Others

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In the case of Chapters 3-8, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
Development of study design, data collection, analysis, manuscript preparation and submission to journals	80%

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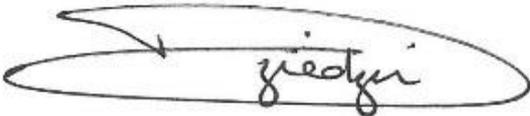
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The undersigned hereby certify that:

- (1) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
- (2) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
- (3) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
- (4) there are no other authors of the publication according to these criteria;
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- (6) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

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Signature 4		Date 23/5/2016

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“You are loved, you are strong, you are powerful and you are worthy of all those who will help you along the way.”

Kurt Fearnley, Pushing the Limits (2014)

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List of Abbreviations

Δ	Change
$^{\circ}\text{C}$	Degrees Celsius
% time	Percent of time
%TfrSat	Percent transferrin saturation
μL	Microlitres
$\mu\text{g.L}^{-1}$	Micrograms per litre
ave.game ⁻¹	Average per game
AFL	Australian Football League
C	Cortisol
CI	Confidence interval
CK	Creatine kinase
CL	Confidence limits
CMJ	Countermovement jump
CV	Coefficient of variation
CWI	Cold water immersion
DXA	Dual-energy X-ray absorptiometry
EAR	Estimated average requirement
ES	Effect size
Fer	Ferritin
g	Force of gravity
g.dL ⁻¹	Grams per decilitre
GPS	Global positioning system
Hb	Haemoglobin
Hct	Haematocrit
HR	Heart rate
hrs	Hours
impacts.min ⁻¹	Impacts per minute
kg	Kilograms
kg m.s ⁻¹	Kilograms per metre per second
km.h ⁻¹	Kilometres per hour
LMI	Lean mass index
m	Metres
MCV	Mean cell volume
min	Minutes
mg	Milligrams
mg.day ⁻¹	Milligrams per day
mL	Millilitres
mL.kg ⁻¹ .min ⁻¹	Millilitres per kilogram per minute
mm	Millimetres

mM	Millimoles
mmol.L ⁻¹	Millimoles per litre
m.min ⁻¹	Metres per minute
m.s ⁻¹	Metres per second
m.s ⁻²	Metres per second squared
NSAIDs	Non-steroidal anti-inflammatory drugs
O ₂	Oxygen
PV	Plasma volume
r	Pearson's correlation coefficient
RBC	Red blood cells
RDI	Recommended dietary intake
RPE	Rating of perceived exertion
RSA	Repeat sprint ability
s	Seconds
SD	Standard deviation
T	Testosterone
T/C	Testosterone to cortisol ratio
Tfr	Transferrin
U.L ⁻¹	Units per litre
VO ₂ max	Maximal oxygen uptake
vVO ₂ max	Velocity at maximal oxygen uptake
VT ₂	Second ventilatory threshold
VT ₂ speed	Speed at second ventilatory threshold
W	Watts
W.kg ⁻¹	Watts per kilogram
WBC	White blood cell
y	Years
Yo-Yo IR1	Yo-Yo intermittent recovery test level 1

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List of Articles Submitted for Publication

- Clarke, AC.,** Anson, J., Pyne, D., Physiologically based GPS speed zones for evaluating running demands in women's rugby sevens, *Journal of Sport Sciences*. 33: 1101-1108, 2015.
- Clarke, AC.,** Anson JM., Pyne DB., Neuromuscular fatigue and muscle damage following a women's rugby sevens tournament, *International Journal of Sports Physiology and Performance*. 10: 808-814, 2015.
- Clarke AC.,** Anson JM., Pyne DB., The effect of running demands and impacts on post-tournament markers of inflammation and haemolysis in women's rugby sevens, *New Zealand Journal of Sports Medicine*. 42: 70-76, 2015.
- Clarke AC.,** Anson JM., Pyne DB., Game movement demands and physical profiles of junior, senior and elite male and female rugby sevens players, *Journal of Sport Sciences*. Epub ahead of print, May 23; 1-7, 2016.
- Clarke AC.,** Anson JM., Pyne DB., Proof of concept of automated collision detection technology in rugby sevens, *Journal of Strength and Conditioning Research*. Epub ahead of print, July 26, 2016.
- Clarke AC.,** Anson JM., Dziedzic CE., McDonald WA., Pyne DB., Females at risk: Iron monitoring of male and female rugby sevens players over an international season. *British Journal of Sports Medicine*. In review (first).

List of Conference Presentations and Proceedings

- Clarke, AC.,** Anson, JM., Pyne, DB., Physiologically-based GPS speed zones for evaluating running demands in women's rugby sevens (abstract), *Be Active - Sports Medicine Australia*. Canberra, Australia, October 2014.
- Clarke, AC.,** Anson, JM., Pyne, DB., Iron deficiency in male and female rugby sevens players over a season (abstract), *Applied Physiology Conference*. Canberra, Australia, November 2014.
- Clarke, AC.,** Anson JM., Pyne DB., Neuromuscular fatigue and muscle damage in women's rugby sevens (abstract), *8th World Congress on Science and Football*. Copenhagen, Denmark, May 2015.
- Pyne, DB., **Clarke, AC.,** Anson, JM., Dziedzic, CE., McDonald, WA., Monitoring iron levels in male and female rugby sevens players over an international season (abstract), *American College of Sports Medicine 63rd Annual Meeting*. Massachusetts, USA, May 2016

CHAPTER ONE

Introduction

Background

In the latest annual report from the Australian Rugby Union, female participation rose by ~30% in 2015 (3). Currently, there are approximately 1.8 million females playing rugby around the world, and women's rugby sevens is considered one of the fastest growing sports worldwide (2). The inclusion of a regular international Women's Rugby Sevens Series from 2013, and involvement in the Olympic Games in 2016 have increased the number of international level competitions. These developments have led to more countries having full-time programs and a greater number of youth players aspiring to be professional female rugby sevens players. Despite this progress, only 25% of rugby sevens research papers (12 studies) involve female players. Until now, because of a lack of female-specific research, reliance has been placed on research derived from men's rugby sevens to inform training, estimate game demands, and implement suitable recovery strategies. This reliance has also precluded exploration of other special considerations pertinent to female players undertaking rugby sevens at all levels of competition.

Given the physiological differences between men and women, it seems likely that the game demands and training requirements of male and female rugby sevens players would differ substantially. Variations in technical and tactical aspects of performance and a lack of traditional, long-term exposure to playing contact sports by females are also likely to produce differences in the game style between males and females. This difference was highlighted in a recent news article (48) by the Australian Women's Rugby Sevens' coach. He considered female players' late introduction to the game made them more interesting rugby players because they don't accept the current way of doing things as being "set in stone" (48). Given these differences in physical, technical, and tactical aspects of play between sexes, it is critically important to view women's rugby sevens as its own entity, and to question practices carried over from the management of male players. To move forward, specific research is needed into women's rugby sevens. This concept of sex-specificity in rugby sevens extends to the training requirements and progression of female players as well as the appropriate monitoring practices for general health and athletic performance.

Statement of the Problem

Despite several studies on the match demands and physical characteristics of male rugby sevens players, a dearth of information is available on female rugby sevens players. Similarly, few research studies have examined male and female players in junior or developing levels of competition, or explored the physiological disturbances that occur following a rugby sevens tournament, where up to six games are played over two consecutive days. This information would assist sex-specific development of male and female players for international representation through the appropriate prescription of training and recovery practices, talent identification, and selection processes. Understanding the specific considerations of female players for the appropriate monitoring of training loads and general health should also improve the management of female players for rugby sevens competition.

Research Objectives

Six sequential studies were formulated to address the shortcomings in the current knowledge, and are presented in Chapters Three – Eight (Figure 1.1). The objectives of each study are presented below:

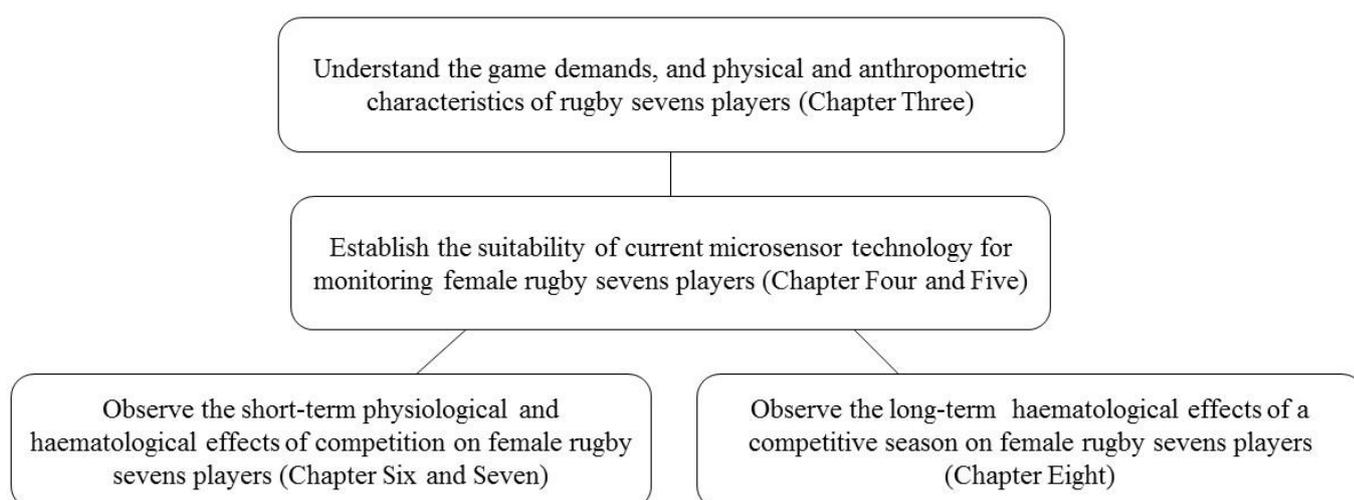


Figure 1.1. Schematic diagram of the flow of experimental chapters (Chapter Three – Eight) within the thesis.

Chapter Three – Quantify the game running movements and anthropometric and physical characteristics of male and female rugby sevens players across three levels of competition (Junior, Senior, Elite).

Chapter Four – Establish a mean physiologically-defined threshold for analysis of high-intensity running using microtechnology units in elite women's rugby sevens players.

Chapter Five – Assess the ability of automated collision detection software in GPSports microtechnology units, in comparison with manually-coded notational analysis, to detect collisions in elite men's and women's rugby sevens.

Chapter Six – Compare and correlate the game movements and subsequent changes in markers of neuromuscular fatigue and muscle damage in State and National representative players following a rugby sevens tournament.

Chapter Seven – Quantify the short-term changes in biochemical and haematological variables of inflammation and haemolysis induced by a women's rugby sevens tournament in State and National representative players.

Chapter Eight – Quantify the direction and magnitude of haematological changes in male and female rugby sevens players over a competitive season, with particular interest in quantifying the incidence of iron deficiencies in female players.

Synopsis of the Thesis

In total, this thesis contains ten chapters. After the Introduction (*Chapter One*), a narrative style Literature Review (*Chapter Two*) provides background information on the game demands and physical attributes of rugby sevens players, with specific consideration of the short- and long-term management of the recovery and health of female players. The experimental chapters of this thesis (*Chapters Three – Eight*) are presented in manuscript format. Each manuscript outlines and discusses the individual methodology and research outcomes of the respective studies separately. Chapters Three, Four, Six, and Seven have been published in peer-reviewed journals. Chapters Five and Eight are currently in the manuscript review process. The General Discussion (*Chapter Nine*) interprets the

collective outcomes of this thesis and provides a summary of the thesis. The final chapter, Practical Applications and Future Directions (*Chapter Ten*), provides practical applications of the research outcomes, acknowledges the limitations of studies within the thesis, and identifies possible areas of future research. To avoid repetition, all references are provided in a single list at the end. Abstracts published or submitted for conference presentations are presented in the Appendices.

CHAPTER TWO

Literature Review

Introduction

Since the announcement that rugby sevens will be included in the Olympic Games schedule from 2016, significant growth and development has occurred in the sport worldwide. Professionalism in rugby sevens has increased rapidly and many countries now have full-time centralised programs to prepare athletes for the Olympic Games and international competitions for both male and female players. Substantial investment is being directed into rugby sevens research to provide a better understanding of the game demands and training requirements to improve the preparation and management of players for competition.

While rugby sevens is derived from the game of rugby union, several key differences distinguish the game demands and physical requirements of rugby sevens players. Rugby sevens consists of seven on-field players per team, played over two seven minute halves. Games are played in a tournament-style format where 2-3 games are played per day over 2-3 consecutive days. With only minor deviations to the rugby union laws of the game, games are played on the same sized field as 15-a-side rugby union, requiring greater field coverage per player. While some men's international tournaments are conducted on consecutive weekends, most tournaments for both the Men's and Women's World Series are separated by 4-6 weeks. Rugby sevens has many unique features which result in marked differences in the game movements, physical characteristics and management of rugby sevens players compared with other football codes.

The style of play in rugby sevens is evolving rapidly. While there have been some developments in the men's style of play (106) in recent years, greater changes have occurred in the women's game (105) (Table 2.1). In the latest (2014-15) Women's Rugby Sevens World Series the average points and tries scored per game are the highest to date. The increase in ball-in-play time and reduced number of rucks, mauls, scrums and lineouts also lends the game to having a more open style of play compared with two seasons previous when the international women's series was first introduced. With more teams turning professional and athletes becoming specialised rugby sevens players, the style of game play in rugby sevens will continue to evolve for both sexes.

Table 2.1. Comparison of match scores, activities and set piece play over three Men's and Women's World Sevens Series from 2012-2015. Results are presented as an average across all teams and tournaments within each season. Data published by World Rugby (105, 106).

	Men			Women		
	2014-15	2013-14	2012-13	2014-15	2013-14	2012-13
Points (ave.game ⁻¹)	36.4	33.0	33.0	34.4	29.4	28.0
Tries (ave.game ⁻¹)	5.8	5.2	5.4	5.6	4.8	4.8
Try rate	1 every 73 s	1 every 83 s	1 every 80 s	1 every 82 s	1 every 89 s	1 every 88 s
Ball in play (% time)	48%	51%	51%	55%	48%	50%
Rucks/mauls (ave.game ⁻¹)	17.2	17.0	17.0	19.0	19.6	21.0
5+ passing movements (rate)	1 in 8	1 in 8	1 in 8	1 in 7.3	1 in 7.6	1 in 9
Scrummings (ave.game ⁻¹)	3.2	3.6	2.8	3.6	4.4	4.6
Lineouts (ave.game ⁻¹)	2.6	2.5	2.4	1.8	2.2	2.2

The majority of male players come from other football codes such as rugby union and rugby league, female players anecdotally transfer from non-contact sports. Given this pattern of recruitment, the development required for female players to understand the technical, tactical and physical nature of rugby sevens means that unique training and management of these players is needed. As most research in rugby codes (rugby sevens, rugby union and rugby league) is predominately on male players, female-specific assessments of game demands, physical characteristics, training requirements, recovery and adaptation are required to better understand the women's game. Some research is available on rugby sevens referees (137, 174, 176) and concussion-incidence rates in male players (63, 118), however, studies on women's rugby sevens are few in number. This review focuses on the game demands and physical attributes of male and female rugby sevens players. The short- and long-term management of female players with regards to recovery and general health are also detailed. This literature review is completed in a narrative style and incorporates all rugby sevens papers (men's and women's) published prior to March 2016. Further, given the emergent nature of rugby sevens research, a more expansive exploration of particular topics and inclusion of sports other than rugby sevens, are presented. In particular, reference to appropriate rugby union and rugby league papers, and key papers on specific topic areas of interest to female rugby sevens players, such as iron monitoring, are included. Three search engines were used (SPORTDiscus, PubMed, Google Scholar) to compile this literature review. Papers were identified by searching for key words such as, but not limited to: rugby sevens, player development, muscle damage, fatigue, recovery, rugby, football, physiology, game demands, iron monitoring, women. Cross referencing with other studies' reference lists was also performed to ensure all relevant studies were included.

Game demands in rugby sevens

Understanding the game demands of rugby sevens allows coaches and support staff to adequately prescribe training for players to meet the physical demands of competition. Knowledge of position-specific requirements and the influence of competition level upon game metrics can enhance the preparation of rugby sevens players. However, the appropriateness of automated methods of quantifying game demands (high-speed running movements and collision events) using microsensor technology in male and female rugby sevens players has not been clearly established.

Game movements of players

Men's rugby sevens

Rugby sevens games are substantially shorter (7 min halves; 10 min halves for finals) than rugby union matches (40 min halves), therefore, the total distance covered by elite male players is correspondingly less in rugby sevens (1200 – 1900 m) (82, 90, 161, 173, 178) compared with rugby union (4500 – 7500 m) (13, 21, 33, 40, 160). However, the relative total distance covered per minute of play in men's rugby sevens (90 – 120 m.min⁻¹) (82, 90, 161, 173, 178) is more than twice that in rugby union (65 – 72 m.min⁻¹) (21, 40), and the work-to-rest ratio also differs (rugby sevens 1:0.5 – 0.6; rugby union 1:4.0 – 5.8; work:rest) (13, 40, 173, 178). Given the generous amount of space available per player in rugby sevens, the average sprint distance is ~20 m for male players, however sprint distances up to 40 m are not uncommon (173, 178). Thus, the game demands of rugby sevens are different to rugby union and require athletes capable of high-speed running movements, and repeated and prolonged sprinting efforts. In rugby union, players have specialised positions, although in rugby sevens this may be less important.

Positional differences

Research in rugby sevens is often limited to small study participant numbers, so characterisation based on playing position is not always possible. Only five papers compare the game demands of backs and forwards in rugby sevens. The first study that observed the game movements of rugby sevens players was conducted in 1996 (157), prior to the sport's inclusion in the Commonwealth Games or establishment of the Sevens World Series. Using video-based notational analysis, elite male forwards spent a greater amount of time jogging and in static poses compared with backs, while there was an unclear difference in the distance covered at high-speed running (157). In more recent research using microtechnology (i.e. global positioning systems, GPS) to monitor running movement patterns, male backs (at elite and provincial competition levels) completed greater total distances, covered greater distances when running at high speed and sprinted more than forwards, despite similar mean heart rates (HR) (95, 173). The similarity in HR between backs and forwards, despite differences in the running demands on players, implies that non-running activities such as tackles and scrums also contribute to the cardiovascular demands, however, this is not easily captured using microsensor technology. In contrast, trivial to small differences are evident between backs and forwards in both running and

non-running activities in elite and provincial male rugby sevens players (82, 162), suggesting that position-specific specialisation is not required in rugby sevens. However, when movement demands are compared between positions over an entire tournament, some differences become more apparent – forwards appear to cover greater total distances and distances at speeds $<5 \text{ m}\cdot\text{s}^{-1}$ (162). Some of these differences may be related to variations between teams, competitions, and playing levels, yet they might also reflect the development of the sport over the last 20 years given increased participation and professionalisation occurring within the current Olympic cycle, and a trend for fewer differences being apparent with more recent studies (82, 95, 162, 173). The time period between some studies are as little as one season, and whether positional differences are based on developments in play or other variations is unknown. As the sport continues to evolve, understanding the magnitude and contributors to positional differences will be helpful for the appropriate training and development of players for improved competitive success.

Level of competition

The majority of game movement studies in men's rugby sevens are on elite level players. Only two papers have compared male elite and provincial level competitions (90, 161). High speed running distances ($>6 \text{ m}\cdot\text{s}^{-1}$), number of sprints, and acceleration and deceleration phases per minute of game time is up to 30% greater for international level players compared with provincial level players (90, 161). Interestingly, the relative total running distance is similar for both playing levels. Understanding the game movement patterns of different playing levels would benefit more specific prescription of training and development of players for future representative opportunities. Given the rapid development of rugby sevens worldwide, the main focus of coaches and support staff has been on the preparation of elite level players. However, to ensure continual progression of the game and to maintain team standings, development of up-and-coming talent and growth of junior player involvement is likely to increase. Only one study is available on junior (under 18 y) male players and shows, not unsurprisingly, that game movements are lower than provincial and elite level players (189). In addition, this study is the only study to compare the running movements of teams of higher and lower rank. More successful teams completed a greater proportion of high intensity running efforts (189). Whether a similar relationship is apparent between running movements and success by teams at the elite level is yet to be determined. Understanding the game demands upon junior level players has

implications for talent identification, training prescription and athlete development and progression.

Non-running characteristics of successful teams

While the running movements of players appear to not be affected by whether the game is a pool or finals match (162), patterns of game play can differ between pool and finals games, as well as between successful and less successful teams. One study has shown pool games to have longer ball-in-play sequences than finals matches (23), while another showed the opposite (162). These contradictory results may be related to the international season that observations were undertaken. The study reporting pool matches as having longer ball-in-play activity was undertaken during the 2011-12 season (23), two years prior to the second study (162). It is possible that aerobic fitness and skill of players improved over the intervening years, with decrements in performance not evident in the latter stages of a rugby sevens tournament today. Ball-in-play time is also greater in international than provincial (161) level games as well as in successful, highly ranked teams compared with unsuccessful teams (92). Winning or maintaining possession during scrums, rucks, and lineouts, entry into the oppositions 22 m zone, a high tackle completion count and conversion of >30% of possession time into point scoring movements, are all associated with success and higher team rankings in men's rugby sevens (91-93, 190). Effective evaluation of team performance following games is needed to identify technical and tactical performance measures required for success.

Women's rugby sevens

Compared with women's rugby union, female rugby sevens players cover less total distance (women's rugby union ~5800 m; women's rugby sevens ~1500 m), but execute greater relative running distances ($67 \text{ m}\cdot\text{min}^{-1}$; $>90 \text{ m}\cdot\text{min}^{-1}$) and percent distance at high-speed ($\sim 3\%$; $>9\%$) respectively (143, 148, 175, 177, 194, 197). In rugby union, female players cover considerably less distance (total and high speed) and have a lower relative running distances than male rugby union players (13, 21, 33, 40, 160). In rugby sevens, only minor variations between sexes are apparent (Table 2.2). While studies (82, 90, 143, 148, 162, 173, 175, 178, 194) report using 'elite-level' players, the competitions vary from the Sevens World Series to the European Championships and other non-disclosed international tournaments. While there is inherent variability from one game to the next,

tournament level and strength of opposition may also influence the running movements of players, and hence confound comparisons between sexes. Given these uncertainties a clear description of differences between men's and women's rugby sevens may not be fully realised. In addition, more research that delineates playing levels will aid in the appropriate prescription of training for specific playing levels based on game movements.

Table 2.2. Game movements of elite male and female rugby sevens players. Data presented as a range of study means.

	Men (82, 90, 162, 173, 178)	Women (143, 148, 175, 194)
Total distance (m)	1221 – 1906	1468 – 1642
Relative total distance (m.min ⁻¹)	91 – 120	95 – 103
High speed running (% , >5 m.s ⁻¹)	6.0 – 17.5	9.3 – 14.0
Sprints (n)	6.5 – 8.5	5.3 – 6.1
Work:Rest ratio	1:0.5 – 1:0.6	1:0.3 – 1:0.4

No research has compared the game demands of position-specific female rugby sevens players, and only two studies have analysed differences in movement patterns between international and provincial level competitions (148, 194). International players cover up to 20% greater total distance, undertake twice as much high-speed running, and complete three times the number of sprints relative to provincial level players (148, 194). While one study showed similar relative running distance (m.min⁻¹) between playing levels (194), Portillo et al. (148) reported that international players had 15% greater relative running distance than provincial level players. No studies have examined junior (under 18 y) female rugby sevens players, nor explored the patterns of play associated with team success. Clearly, more research is required in women's rugby sevens to understand the game demands and position-specific requirements of players. This knowledge is required across all playing levels (junior, provincial, elite) to more effectively develop players for the demands of the game.

Quantifying game demands

While there has been substantial research into the demands of the game on rugby sevens players, generalisations and assumptions underlie data collection methodologies. The two most common methods of time-motion analysis for monitoring the external running loads of players in field-based team sports are video-based notational analysis and microsensor

technology (GPS units). Given the labour-intensive and time-consuming nature of notational analysis, many professional football teams favour GPS, due to its ease of use and ability to provide real-time feedback to coaches. A number of studies have examined the validity and reliability of GPS units in measuring speed, distance and acceleration (34, 84, 102, 103, 153, 191, 195, 199). As technology has evolved, the validity and reliability of these devices has improved (102, 103). While deemed acceptable for use in team-sport activities, the validity and reliability of GPS units decline with increasing running speeds and change of direction movements (34, 84, 102, 103, 153, 191, 195, 199). With the rapid development and use of GPS technology in sport, in practice data is often used before assessment of its quality and applicability is completed. Key issues are the appropriate speed thresholds used to obtain meaningful data on high intensity running, the ability of such devices to report on impacts and collisions, and whether the same thresholds are suitable for both sexes and different game formats.

High-intensity versus high-speed running

An advantage of GPS data is the ability to characterise time and distances spent within specific speed thresholds, from walking to sprinting (12). GPS variables of average speed and total distance are relatively straightforward to use, whereas high intensity running and sprinting are more contentious given the various speed thresholds used when defining this measure. In men's rugby sevens, the threshold commonly used for high-intensity running is $5 \text{ m}\cdot\text{s}^{-1}$ (90, 178). This value is likely based upon movement studies in men's rugby union (40) and rugby league (14), but is higher than that used in Australian Football ($4.2 \text{ m}\cdot\text{s}^{-1}$) (132). Current speed thresholds for high-intensity running appear to be arbitrarily set, with little apparent physiological evidence (38). This threshold, then, is actually a measure of high-speed, rather than high-intensity, running. A number of alternative physiologically-based methods have been proposed as potentially advantageous in determining high-intensity thresholds using a player's: ventilatory threshold (4, 41, 120), a percentage of their maximal running velocity (154), or average velocity distribution curves (53). The use of these methods would allow for individualisation of thresholds for each player, providing a more accurate estimation of the high-intensity running demands for individuals (120, 154). The application of such methods are still in the development stages and factors such as playing level, phase of competitive season, and sex may necessitate some alteration or adjustment of the thresholds obtained.

Currently, the majority of women's rugby sevens research use the same high-intensity threshold as men's rugby sevens ($5 \text{ m}\cdot\text{s}^{-1}$) (148, 175). However, differences in absolute physiological capacities between sexes (136) infers that a common threshold for high intensity running might underestimate the work completed by female players. Using average velocity distribution curves of competitive matches in women's soccer and hockey, Dwyer and Gabbett (53) recommend the use of lower speed thresholds ($3.4 - 3.7 \text{ m}\cdot\text{s}^{-1}$), which better correspond to high-intensity efforts by female players. As there is little research using GPS in other women's team-sports, developing and evaluating physiologically-based thresholds for high intensity running in women's rugby sevens players is warranted as sex-specific thresholds may be needed.

Detecting impacts and collisions

With improving technology, microsensor units are also able to detect impacts (g-forces experienced during player movements) and collisions (physical contact between two or more players) using tri-axial accelerometer data. This information is useful for quantifying impacts and collisions that contribute to the overall workload of players and can inform training prescription for adaptation, return-to-play, and reducing the incidence of overtraining injuries. The reporting of impacts sustained during matches is available in men's rugby sevens (173) and indicates little difference in the number of recorded impacts ($>7 \text{ g}$ -force) between forwards and backs. However, forwards completed $\sim 40\%$ more tackles (7.4 ± 1.8 tackles per game, compared with 4.1 ± 2.4 tackles per game for backs; mean \pm SD) as well as being involved in ~ 4 scrums per game (173). In men's rugby league, a poor relationship was observed between the number of impacts reported using microtechnology and the number of hit-ups recorded via video-based notational analysis (129). Given the likelihood of non-contact events such as a heavy foot strike, change of direction or dive on the ground eliciting up to 6 g -force (69), the measurement of impacts is unable to differentiate high impact running movements from physical collisions with the opposition. Despite this shortcoming, quantifying the impact forces imposed on players during rugby sevens is beneficial for the preparation and management of players following competition given that $>75\%$ of acute injuries originate during contact or tackle events (62, 118, 119). No research has investigated the impacts experienced in women's rugby sevens matches, however, given the incidence of injuries during games being reportedly higher in

women's rugby sevens than women's rugby union or men's rugby sevens (66), this information, if forthcoming, may help reduce the injury rates in this population.

While impacts derived via microtechnology are reported as a g-force rating which potentially might quantify a wide range of events from a heavy foot-strike to a very severe tackle, a microtechnology-detected collision can supposedly detect when specific collisions occur with another player. The applied use of automated collision detection technology is relatively new, and removes the reliance on video-based notational analysis, a time-consuming and labour-intensive subjective process, to obtain this information. A commercially available microtechnology unit (MinimaxX S4, Catapult Innovations, Australia) which includes a tri-axial accelerometer, gyroscope and magnetometer to identify and quantify collisions, has been deemed valid when compared with video-based analysis in simulated rugby union activities (206). However, not all commercially available GPS units include a gyroscope or magnetometer. To overcome this limitation, specialised algorithms have been developed using only tri-axial accelerometer data, based on common movement patterns during collision events in rugby union (GPSports) (108). Limited research is available utilising this type of microtechnology-detected collision data and further investigation is required to assess the utility of these measurements. Furthermore, given the differences between rugby union and rugby sevens, collision events likely present differently (predominately one-on-one high speed tackles in rugby sevens compared with multiple player collisions at lower speed in rugby union) and this may affect the ability of the algorithm to detect when collisions occur in rugby sevens. It is unknown whether the algorithm developed for males is suitable for female players, given differences in physical size, strength and possibly tackle techniques.

Summary

Men's rugby sevens games are faster with a greater proportion of high speed running movements than men's rugby union. Positional differences are trivial to small in men's rugby sevens, while game movements increase from provincial to elite level competition. Little is known about the characteristics of the women's game although preliminary research indicates similar game movements to those of male players. However, more research is required to quantify the game demands of men's and women's rugby sevens at both junior and provincial competition levels to enhance the development of players. In

addition, more research elucidating positional differences, especially in the women's game, is required to develop targeted training programs for forwards and backs.

GPS technology has the potential to quantify game demands, however, care must be taken during interpretation. The same speed threshold value for high-intensity running may not be applicable to both the men's and women's game. In addition, microtechnology collision-detection algorithms developed for one sport may not be appropriate for another. Two areas for further research are, firstly, the threshold characterising high-intensity running efforts in women and, secondly, the validity and reliability of microtechnology detection of impacts and collision in men's and women's rugby sevens games.

Physical characteristics of a rugby sevens players

Game demands dictate, in part, the anthropometric and physical characteristics of successful players. Coaches monitor the anthropometric and physical characteristics to select and recruit players, monitor training-induced adaptations, and assess players returning from injury. Measuring the anthropometric and physical characteristics of players ensures individuals are ready for competition, with well-developed physical attributes linked to successful team performance (140). A number of anthropometric characteristics and physical attributes evident in rugby union players are beneficial in rugby sevens players. Positional and/or competition level differences also influence anthropometric and physical qualities of players as well as game involvements and running movements during competition.

Anthropometry

Male rugby sevens players

The anthropometric profiles of elite male rugby sevens players are presented in Table 2.3. Only three papers have compared the anthropometric measures of height, body mass, body fat and lean mass between positions in elite men's rugby sevens (62, 131, 157). Despite trivial to small positional differences in game movements, rugby sevens forwards appear to be generally taller (2-5%; $\sim 185.7 \pm 4.8$ cm; $\sim 179.1 \pm 6.2$ cm, percent difference; forwards; backs, mean \pm SD), heavier (7-20%; $\sim 95.4 \pm 7.0$ kg; $\sim 84.6 \pm 7.1$ kg), have a higher percentage of body fat (6%; $12.1 \pm 2.2\%$; $11.4 \pm 2.5\%$), and greater lean mass (14%;

57.8 ± 6.2 kg; 49.5 ± 7.4 kg), than backs (62, 131, 157). However, when corrected for body mass, differences in muscle and fat mass become negligible (157). Similar positional differences have also been reported when elite and provincial level players are combined (164). Rugby sevens players (backs and forwards) are similar in physical size and stature to rugby union backs, and are considerably shorter, lighter and leaner than rugby union forwards (61, 152, 171). One study that directly compared the body composition of elite male rugby sevens and rugby union players, using dual-energy X-ray absorptiometry (DXA), showed that rugby union backs were moderately heavier than rugby sevens backs, but similar to rugby sevens forwards (89). Comparing positions within rugby sevens using DXA, forwards are heavier and have greater fat mass, muscle mass and bone mineral mass. However, when tissue mass is reported as a proportion of total mass for each body region, these differences became unclear (89).

Table 2.3. Anthropometric profile of elite male rugby sevens players. Data are presented as mean \pm SD.

	Age (yrs)	Height (cm)	Body Mass (kg)	Fat free mass (kg)	Body fat (%)	Sum of 7 Skinfolds (mm)	LMI (kg.mm ^{-0.14})
Crewther et al., 2013 (35) (n=12) ¹	23.6 \pm 3.2	180.3 \pm 6.0	92.4 \pm 7.2	76.5 \pm 5.5	16.9 \pm 3.2		
Elloumi et al., 2012 (57) (n=16) ²	23.8 \pm 3.1	183.1 \pm 0.1	87.3 \pm 7.4	75.9 \pm 6.1	13.1 \pm 2.7		
Higham et al., 2013 (94) (n=18) ³	21.9 \pm 2.0	183.0 \pm 6.0	89.7 \pm 7.6			52.2 \pm 11.5	51.7 \pm 4.3
Mitchell et al., 2015 (131) (F, n=7; B, n=7) ³	21.4 \pm 2.2	F: 185.2 \pm 4.2 B: 181.1 \pm 7.8	F: 95.1 \pm 6.7 B: 89.1 \pm 6.3			F: 58.2 \pm 14.2 B: 50.8 \pm 7.6	F: 55.5 \pm 3.6 B: 51.8 \pm 3.6
Reinzi et al., 1999 (157) (n=27*) ⁵		F: 184.6 \pm 4.6 B: 175.6 \pm 5.1	F: 93.5 \pm 7.8 B: 78.6 \pm 7.1	F: 57.8 \pm 3.5 B: 49.4 \pm 3.5	F: 12.1 \pm 2.2 B: 11.4 \pm 2.5		
Ross et al., 2015 (164) (n=22) ¹	24.0 \pm 3.7	186.0 \pm 5.7	95.7 \pm 7.1			61.6 \pm 10.5	
Suarez-Arrones et al., 2013 (173) (n=10) ⁴	27.4 \pm 1.6	180.4 \pm 7.8	87.9 \pm 11.0			61.6 \pm 6.0*	
Fuller et al., 2010 (F, n=88; B, n=162) ⁵	F: 23.8 \pm 2.9 B: 22.8 \pm 3.1	F: 187.5 \pm 5.8 B: 180.1 \pm 6.4	F: 97.7 \pm 7.2 B: 86.0 \pm 7.8				

Superscript numbers refer to the nationality of players as follows: 1, New Zealand; 2, Tunisia; 3, Australia; 4, Spain; 5, various teams included/nationality not defined. F: forward; B: back. When playing position is not specified, data are reported as the mean of all players. *Number of participants per playing position not given. When anthropometric measures were assessed over a given time, the initial subject measurements are reported.

Only one study has reported the anthropometric characteristics of male rugby sevens players at a provincial level (164), and little research is available on the influence that players' anthropometry has on game performance or match outcome. International-level male rugby sevens players are taller and heavier, with a lower skinfold thickness, than provincial level players (164). Similar findings have been observed in men's rugby union for height, however, body mass increased with playing levels in rugby union forwards only (50). Since 1975, the height and body mass of rugby union players has continued to increase, and team success is linked to superior player size and stature (140). In rugby sevens, the only study to relate player anthropometric measures with game movements observed a negative correlation between high-speed running and muscle mass ($r = -0.55$) (157). However, this study was conducted almost 17 years ago where a greater variation in player size (with more traditional forwards and backs roles) was more apparent (157). In this study (157), while forwards had similar physical characteristics to modern day rugby sevens players, backs were substantially shorter, lighter, and with less muscle mass. More recent research has shown favourable associations between anthropometric characteristics (height, mass, skinfold thickness) and physical performance (test) measures (speed, aerobic capacity, lower body power) in male rugby sevens players (94). Whether anthropometric measures relate to specific game movements of players in rugby sevens is yet to be determined. Understanding the anthropometric qualities of rugby sevens players at various competition levels and how these might change is also unknown. This knowledge could enhance training prescription, monitoring of adaptations, talent identification and player selection for tournaments.

Female rugby sevens players

Anthropometric profiles of elite female rugby sevens players are presented in Table 2.4. Interestingly, players from Australia and Canada, top tier teams in the Women's World Series, trend towards being taller (166 – 170 cm) and heavier (69 – 73 kg) (5, 27, 77, 79) than players from Spain, France (both observed competing at European Championships) and Japan (height, 164 – 167 cm; body mass 60 – 68 kg) (43, 139, 143, 148, 175). While no substantial differences in anthropometric profiles were evident between players selected or not selected for tournaments at an international level within the same squad (79), competition success in men's rugby union has previously been linked to taller and heavier teams (140). Height and body mass are likely advantageous within rugby sevens, however,

the relationship between player anthropometry and game movements in women's rugby sevens has yet to be quantified.

Only two studies have compared the positional differences in anthropometry in women's rugby sevens (5, 139). While one study showed forwards to be moderately taller and heavier, with greater skinfold thickness (5), another showed no difference in height or percent body fat, with differences only apparent in body mass and lean muscle mass (139). Compared with women's rugby union and rugby league players, female rugby sevens players (backs and forwards) are similar in height and body mass to female rugby union/league backs (height, 161 – 170 cm; body mass, 63 – 68 kg), but weigh less than forwards (75 – 79 kg) (67, 87, 88, 177). Female rugby sevens players, however, are leaner (sum of 7 skinfold thickness, 84 – 95 mm) (5, 27, 79) than both rugby union and rugby league backs (89 – 115 mm) and forwards (99 – 141 mm) (67, 87, 88, 177). More research is required to understand differences in the anthropometric characteristics of backs and forwards in women's rugby sevens. Given greater positional differences present in a top tier women's rugby sevens team, larger anthropometric differences between positions may be advantageous. Furthermore, no research has quantified the anthropometric profiles of female rugby sevens players at provincial or junior (under 18 y) levels of competition. This information would be particularly beneficial for the development and progression of female rugby sevens players as they transition to higher levels of competition, and for talent identification purposes.

Table 2.4. Anthropometric profile of elite female rugby sevens players. Data are presented as mean \pm SD.

	Nationality (participant numbers)	Age (y)	Height (cm)	Body mass (kg)	Body fat (mm or %)
Agar-Newman et al. (5)	Canada (F, n=11; B, n=13)	22.8 \pm 4.0	F: 170.5 \pm 4.3 B: 166.3 \pm 6.0	F: 72.9 \pm 4.8 B: 66.4 \pm 3.5	F: 95.0 \pm 12.3 mm B: 84.4 \pm 26.1 mm
Ohya et al. (139)	Japan (F, n=11; B, n=12)	23.1 \pm 4.1	F: 166.2 \pm 3.5 B: 164.0 \pm 5.5	F: 68.2 \pm 8.4 B: 60.6 \pm 3.6	F: 18.1 \pm 3.5% B: 15.4 \pm 3.1%
Goodale et al. (79)	Canada (n=24)	24.3 \pm 3.1	167.7 \pm 6.7	70.0 \pm 4.9	86.8 \pm 11.2 mm
Clarke et al. (27)	Australia (n=22)	25.0 \pm 5.0	168.0 \pm 6.0	69.0 \pm 7.0	85.0 \pm 15.0 mm
Del Coso et al. (43)	Spain (n=16)	23.0 \pm 2.0	166.0 \pm 7.0	66.0 \pm 7.0	16.6 \pm 2.8%
Portillo et al. (148)	Spain (n=10)	26.3 \pm 4.1	166.7 \pm 6.7	65.4 \pm 5.0	19.3 \pm 4.1%
Gathercole et al. (77)	Canada (n=12)	23.6 \pm 4.3	169.0 \pm 5.6	69.5 \pm 4.9	
Paquet et al. (143)	France (n=10)	22.0 \pm 6.0	166.8 \pm 2.8	61.9 \pm 6.9	
Suarez-Arrones et al. (175)	Spain (n=12)	27.8 \pm 4.0	165.5 \pm 6.2	63.7 \pm 4.8	

Body fat is presented as either the sum of seven skinfold sites (mm), or as a percentage of total body mass (%). F: forward; B: back. When playing position is not specified, data are reported as the total participant means.

Physical Characteristics

Aerobic capacity

Research in men's rugby sevens shows little consistency in the methods undertaken to assess players' aerobic capacity, however, relationships between different aerobic tests and game involvements are apparent. Treadmill testing using gas analysis to measure players' maximal oxygen uptake ($\text{VO}_2 \text{ max}$) indicates a mean absolute capacity of $4.80 \text{ L}\cdot\text{min}^{-1}$ (94) and a relative $\text{VO}_2 \text{ max}$ between $52 - 56 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (82, 94, 173, 178). This absolute value is lower than that in male rugby union backs and forwards, however relative to body mass, this difference becomes unclear (40, 125). To avoid the need for time-consuming laboratory-based testing, field testing protocols for measuring aerobic fitness in team-sports are commonly used in men's rugby sevens. These protocols include the Yo-Yo intermittent recovery test (Yo-Yo IR) level one (94) and level 2 (57), and the multi-stage shuttle run or 'beep' test (163, 164). The relative $\text{VO}_2 \text{ max}$ of male rugby sevens players largely correlates with Yo-Yo IR1 performance ($r = 0.60$), and negatively correlates with sprinting (10 m and 40 m) and repeat sprint ability ($r = -0.60$ to -0.38) (94). Yo-Yo IR1 performance, on the other hand, has an unclear correlation with sprinting and repeat sprint performance ($r = -0.19$ to -0.09) (94). While no research has correlated players' aerobic capacity with running movements during games, positive correlations ($r = 0.34 - 0.38$) are apparent between maximal aerobic capacity and effective attacking and defensive rucks, as well as overall work rate in men's rugby sevens (163). Only one study has investigated positional differences in aerobic capacity between male rugby sevens backs and forwards and found no clear difference (multi-stage shuttle run test – backs, $2322 \pm 289 \text{ m}$; forwards, $2360 \pm 337 \text{ m}$) (164). On the other hand, a large difference between international ($2563 \pm 197 \text{ m}$) and provincial ($2164 \pm 288 \text{ m}$) level players was evident (164).

Characterising the aerobic capacity of women's rugby sevens players is limited to only a few studies. The relative $\text{VO}_2 \text{ max}$ of female players is $46.5 - 51.1 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (27, 175), which is lower than male rugby sevens players, similar to elite female soccer (98, 124) and hockey (68, 109) players, and greater than female rugby union (88) and rugby league (67) players. Field-based aerobic fitness tests, including the Yo-Yo IR1 ($\sim 1200 \pm 190 \text{ m}$) (27, 194) and a 1600 m test ($\sim 380 \pm 25 \text{ s}$) (5, 79), have also been used in women's rugby sevens. Only one study has compared backs and forwards and reveals small differences in the average speed over 1600 m (5). Substantially greater aerobic fitness was observed in

international level players compared with developmental players (194). Within the same international squad, those selected to play more game time during the season also have better aerobic fitness (79). Given Yo-Yo IR1 performance is positively correlated with total distance ($r = 0.49$), average speed ($r = 0.62$) (27), and high intensity running distance ($r^2 = 0.30$) (194) during games in women's rugby sevens, having well-developed aerobic fitness appears beneficial. More research is required to determine the magnitude of positional differences in female player's aerobic capacity and the extent to which it influences the game movements of players. Given the nature of rugby sevens, with multiple games played per day over consecutive days, players' aerobic capacity may influence their ability to recover following each game. Poorer aerobic fitness may negatively affect subsequent game performance.

Speed and repeat sprint ability

Sprinting ability over both short and longer distances is highly desirable in rugby sevens given typical sprint distances are between 20 – 40 m during a game (178). Quicker initial sprint time (0 – 10 m), shorter total sprint time (0 – 40 m), higher maximum velocity and greater momentum (velocity x body mass) are all desirable attributes in rugby sevens players. In men's rugby sevens, sprinting ability largely correlates with the number of line breaks, defenders beaten and tackle effectiveness (163). However, limited research is available comparing the positional differences in sprint ability for male rugby sevens players. One study showed that backs at elite and provincial levels of competition are moderately faster than forwards in both short (10 m sprint, backs 1.69 ± 0.06 s; forwards 1.75 ± 0.08 s) and long (40 m sprint, backs 5.09 ± 0.16 s; forwards 5.22 ± 0.22 s) sprint distances (164). Moderate to very large differences (up to 4%, or 0.23 s) are also apparent in sprinting ability between provincial and elite level male players (164). Male rugby sevens players appear to be faster than rugby union players, particularly when comparing forward positions between the two codes over longer (40 m) sprinting distances (Figure 2.1). In rugby union, player momentum over 30 m is approximately 650 kg.m.s^{-1} for forwards and 570 kg.m.s^{-1} in backs (152). In rugby sevens, initial sprint momentum over the first 10 m is 550 kg.m.s^{-1} (163) and final momentum (during 30 – 40 m split) is 820 kg.m.s^{-1} (94). The greater final momentum in rugby sevens players is likely due to differences in sprint distance and the method used to calculate momentum. The final momentum in rugby sevens is calculated using the speed between the 30 and 40 m split,

whereas in rugby union the velocity over the whole 30 m sprint is used. Hence a lower maximal player momentum is typically reported in rugby union. No research has quantified differences in momentum between playing positions in men's rugby sevens.

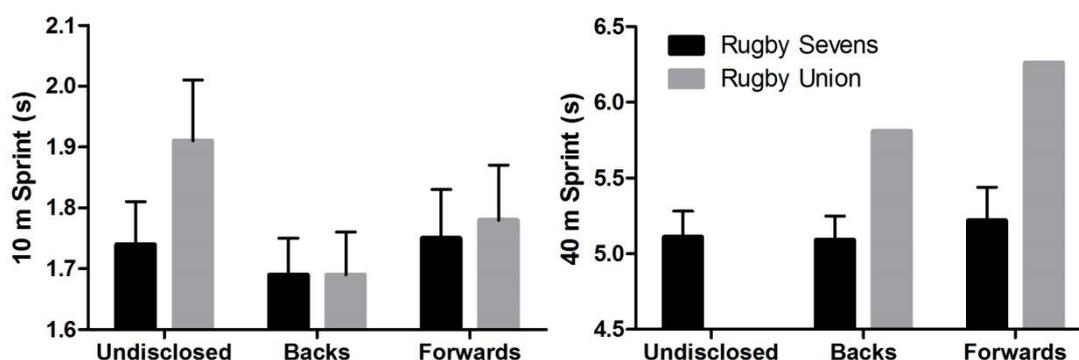


Figure 2.1. Sprint differences between male rugby sevens and rugby union players (57, 86, 94, 158, 163, 164, 170). Data presented as mean and SD. SD not available for rugby union 40 m sprint times. No undisclosed positional data available for male rugby union players' 40 m sprint time.

In women's rugby sevens little research is available comparing the positional differences and differences in competition level for players' sprinting ability. Compared with women's rugby union, female rugby sevens players appear faster, particularly forwards (Figure 2.2) (5, 88). Women's rugby sevens players are also substantially faster than elite women's field hockey players (139). While one study showed moderate differences in speed over 40 m between female rugby sevens backs and forwards (5), another showed no positional differences over 10 and 50 m (139). Similarly, while there is no clear difference in sprinting ability between players within the same squad who played a high or low number of international games (79), international players ($27.3 \pm 0.7 \text{ km}\cdot\text{h}^{-1}$) are faster than their developing teammates ($26.0 \pm 1.5 \text{ km}\cdot\text{h}^{-1}$) (194). Maximal player momentum differentiates those players selected to play international tournaments within a squad (79), as well as between backs and forwards (5). With the greater amount of space available per player, and the trend for teams to keep the ball alive rather than going into contact (as is common in rugby union) (105), speed is a desirable trait for both positional groups in women's rugby sevens. More research is required to understand the speed qualities of

provincial/developing players and whether substantial positional differences are apparent at lower competition levels. With increased professionalisation of rugby sevens, the physical characteristics of elite level female players may become more homogenous and differences between positions less obvious.

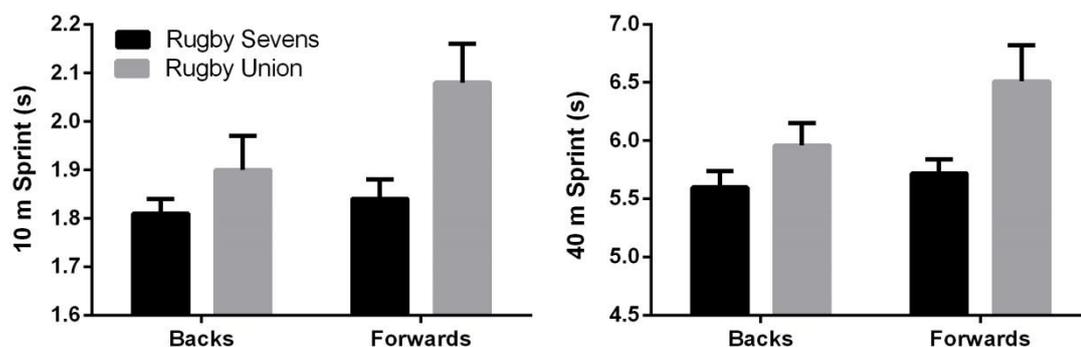


Figure 2.2. Sprint differences between backs and forwards in women's rugby sevens and rugby union players (5, 88). Data presented as mean and SD.

Repeat sprint ability (RSA) is another highly desirable attribute in rugby sevens players and moderately correlates with overall work rate in men's rugby sevens (163). Using a 6 x 30 m repeat sprint test, male rugby sevens players' repeat sprint results are largely positively correlated with 10 and 40 m sprint times ($r = 0.80 - 0.97$) and negatively correlated with maximum velocity ($r = -0.88$) (94), meaning that faster players also have favourable repeat sprint ability. On the other hand, there was only a trivial correlation between RSA and Yo-Yo IR1 performance ($r = 0.00$) or velocity at VO_2 max ($r = 0.03$) (94), indicating that RSA and aerobic capacity are independent attributes. No difference is evident between backs (5.55 ± 0.21 s, mean sprint time for 10 x 40 m sprints) and forwards (5.59 ± 0.22 s), however a very large difference is apparent between international (5.43 ± 0.13 s) and provincial (5.76 ± 0.14 s) level male players (164). Only one study has used a repeat sprint (6 x 30 m) test in female rugby sevens players (43) and, regardless of caffeine intake, the mean maximum running speed was ~ 25 km.h⁻¹. Further research on the requirement for players to have well developed RSA, and the link between this attribute and game performance, would be worthwhile in both men's and women's rugby sevens for the appropriate assessment and development of players.

Strength

The involvement of players in tackling and wrestling activities to maintain possession of the ball necessitates well developed upper and lower body strength in players. Despite this, few studies have quantified in detail the strength characteristics of rugby sevens athletes. Only one study reports the lower body strength characteristics of male rugby sevens players (131). While forwards had greater absolute lower body strength in season (forwards 159 ± 23 kg; backs 146 ± 21), when observed relative to body mass lower body strength of backs and forwards is similar (1.7 W.kg^{-1}) (131). Absolute upper body strength is also similar between backs and forwards (131, 164) in a maximum bench press test. However, when expressed relative to body mass, backs may actually have slightly higher relative upper body strength. Given that during a game of rugby upper and lower body strength is used to displace the opposition, absolute strength is likely more important than relative strength. Despite this assertion, measures of relative strength are still useful for the strength and conditioning coach to track improvements in strength when combined with any decrements in body mass. Small to trivial correlations are evident between the upper and lower body strength of male rugby sevens (163) and rugby union (170) players with player involvements during games. Likely, this outcome is related to the relatively uniform characteristics of players at an elite level, combined with high between-game variability. In instances where strength is advantageous, other technical and tactical considerations could influence performance metrics and lower the observed correlations. Further research is required to understand the requirement of strength for performance in men's rugby sevens.

Across a season, lower body strength appears to remain relatively constant, while upper body strength improves from initial pre-season to late in the competitive season in elite men's rugby sevens (131). Following a 6-week strength program, club-level male rugby sevens players improved upper and lower body strength by up to 13%, while reducing their body fat by 1% (35). The initial lower body strength of club level players (back squat, 144 ± 22 kg) is similar to elite level rugby sevens backs and slightly below elite level forwards (35, 131). However, following the 6-week training program focussing on strength improvements, club-level players improved their lower body strength, ending up stronger than elite backs and forwards during any time-point in the season (35, 131). Elite-level players likely focus training sessions on developing a range of physical and technical

performance aspects, therefore having a lower emphasis on strength gains compared with the observed 6-week intensive training program in club-level players (35). The upper body strength of elite rugby sevens players appears to be up to 18% greater than provincial and club level players (35, 131, 164). Across a competitive season and between playing levels, upper body strength may be more important than lower body strength for successful performance in men's rugby sevens. To date though, no research has quantified relationships between upper body strength and game involvements or running movements in rugby sevens.

Only two studies have characterised the strength characteristics of female rugby sevens players. Forwards appear to have small to moderately greater lower (front squat, forwards 85 ± 6 kg; backs 83 ± 11 kg) and upper (bench press, forwards 69 ± 7 kg; backs 62 ± 7 kg) body absolute strength (5). When adjusted for body mass, however, differences in upper body strength become trivial, while lower body strength is relatively greater (small – moderate) in backs. Comparing players within the same training squad, those selected to play more international tournaments had 6-10% greater upper body strength (absolute and relative), while lower body strength was similar between the groups (79). The upper body strength of female rugby sevens players is greater than reported in women's rugby union (88). The greater strength of female rugby sevens players compared with rugby union players, opposite to men's rugby sevens and rugby union, is likely due to the difference in professional status of these two sports. While men's rugby union is a highly competitive professional sport, women's rugby union is non-professional and played less frequently. In contrast, women's rugby sevens is a professional sport played in many countries worldwide. Players are employed as full-time athletes and the strength and physical capacities of these players are specifically developed, so it is not surprising that elite rugby sevens female player have greater strength characteristics than their female rugby union counterparts.

Power

Power is needed to make effective tackles, break through the defence and fend off opposing players. While strength in rugby sevens appears to focus on the upper body region, power is often reported only in the lower body. A number of different tests have been used to measure lower body power in male rugby sevens players: countermovement jump (CMJ)

testing (weighted and unweighted) using a linear force transducer (131, 164), a horizontal jump test (single or multiple jumps, measuring distance) (57, 164), and, a vertical jump test (measuring height) (94). The lower body power of male rugby sevens players derived from a range of methods is displayed in Table 2.5. Horizontal jump performance correlates positively with tackle score (largely), defenders beaten and dominant tackles (moderately), while CMJ performance is moderately correlated with effective attacking and defensive rucks (163). Unclear or small positional differences appear in most lower body power characteristics for male rugby sevens players (131, 164), except for absolute peak power during a weighted CMJ when forwards performed moderately better (164). Elite players have 15-30% greater lower body power than provincial level players (164), and similar lower body power to rugby union players (9, 86). Despite research in male rugby sevens players showing that circadian rhythm can alter the lower body power output by up to 5% (mean AM peak power output 5200 ± 360 W; mean PM peak power output 5400 ± 360 W) (202), the majority of studies reporting peak power in male rugby sevens players do not specify the time of day that testing has been undertaken (57, 94, 131, 164). While this is of little concern for comparative studies, when tracking player developments over a season the consistent scheduling of physical testing is important.

The most common form of lower body power testing with female rugby sevens players is a horizontal jump test. In female players, horizontal jumping ability has a large positive correlation with both initial and maximal sprinting speed (6). No substantial differences are apparent between positions (forwards 228 ± 9 cm, backs 229 ± 11 cm) (5) or between players with high (227 ± 9 cm) and low (230 ± 11 cm) international playing minutes (79). Similarly, no positional differences were observed for the height reached during a CMJ (forwards 38 ± 4 cm, backs 38 ± 4 cm) (139). Only one study has accounted for body mass when reporting lower body power, indicating that female rugby sevens players have a relative peak power of 57 ± 5 W.kg⁻¹ (77). As such, the lower body power of female players is substantially lower than male rugby sevens players, even when reported relative to body mass (131, 164). Studies in women's rugby union (87, 88) and rugby league (67) have only measured lower body power using a vertical jump test and so direct comparisons cannot be made. Further research detailing the lower body power of female rugby sevens players, whether positional differences are apparent and the difference between elite and provincial level players will inform prescription of strength and conditioning programs. Linking lower

body power with game movements will also improve understanding of these relationships in female rugby sevens players.

Summary

The physical and anthropometric characteristics of male and female rugby sevens players appear superior to male rugby union and other female team-sport players. Positional differences are unclear or trivial for most anthropometric and physical qualities in elite men's and women's rugby sevens. Larger differences are apparent between competition levels, however, only a small number of studies have been conducted in provincial-level players and no research is available on junior level players. Relatively few studies have quantified the strength and power characteristics of rugby sevens players and further research is required in this area for both male and female players. A more comprehensive understanding of the anthropometric and physical characteristics of rugby sevens players, and the presence of any subtle positional or competition level differences, would enable coaches and strength and conditioning staff to better prepare athletes for their roles and level of competition.

Table 2.5. Power characteristics of male rugby sevens players. Data presented as mean \pm SD.

	Competition Level	Testing method	Measurement	Results	
				Backs	Forwards
Mitchell et al. (131)	Elite (B, n=7; F, n=7)	CMJ (unweighted)	Jump height (cm)	52.0 \pm 8.0	46.0 \pm 4.0
			Peak Power (W)	7750 \pm 1240	7780 \pm 1730
			Relative peak power (W.kg ⁻¹)	87.7 \pm 13.4	81.8 \pm 17.4
			Peak power (W)	7110 \pm 1620	7970 \pm 1840
Ross et al. (164)	Elite + Provincial (B, n=37; F, n=28)	CMJ (unweighted) CMJ (50 kg weighted) Horizontal Jump (single)	Relative peak power (W.kg ⁻¹)	79.6 \pm 13.8	81.8 \pm 17.3
			Peak Power (W)	6240 \pm 99	7180 \pm 1490
			Relative peak power (W.kg ⁻¹)	67.6 \pm 8.6	69.8 \pm 10.5
			Distance (m)	2.60 \pm 0.16	2.54 \pm 0.19
Elloumi et al. (57)	Elite (n=16)	Horizontal Jump (5 jump test)	Distance (m)		11.6 \pm 0.6
Higham et al. (94)	Elite (n=16)	Vertical Jump	Height (cm)		66.3 \pm 7.2

CMJ: countermovement jump. When multiple results available for same group of players, initial results are reported.

Effective management of players

A sound knowledge of game demands and physical characteristics of developing and elite players guide the prescription of training, however, many other factors also contribute to competitive success and the effective management of players. Fortunately, despite a large amount of international travel being undertaken throughout a competitive rugby sevens season, final tournament rankings and injury rates do not appear to be negatively affected by flight duration or the number of time zones crossed (64). However, the nature of rugby sevens tournaments, with multiple games per day over two to three consecutive days, can compromise neuromuscular function and induces muscle damage (203). Understanding and monitoring player loads during training and competitive phases, along with the specific nutritional requirements of players, provides a framework for promoting optimal health and player performance.

Physiological disturbances following games

Neuromuscular function

Impaired neuromuscular function results in an inability to produce sufficient force and power in subsequent movements. A commonly used method for measuring neuromuscular function is via a CMJ test. Following a game of rugby union or rugby league, neuromuscular function can be impaired by up to 40% (126, 204) and remains impaired 36 – 48 hours post game (126, 129, 204). In rugby league, reductions in peak power and peak rate of force development during a CMJ correlates with the total number of impacts recorded using GPS (126). Only one study has measured the neuromuscular function of male rugby sevens players following a tournament (six games over two days) and reported a 30% decline in CMJ performance (203). Impaired performance is evident 60 hours post tournament, and can remain lower than pre-competition levels for up to a week (203). However, in this study minimal recovery interventions were employed following the rugby sevens tournament (203), and the continuing impaired CMJ performance is likely a worst case scenario. Despite this, a two-day tournament of rugby sevens appears to have a similar effect on players' neuromuscular function as one game of rugby union or rugby league (126, 204), and may require specific consideration if followed by another (paired) tournament a week later. Various recovery strategies, such as cold water immersion (CWI), compression garments, and massage (149), have been used to reduce the negative effects

of competition in other sports, however, these are yet to be investigated in rugby sevens. No research is currently available in regards to the effect of rugby sevens games on the neuromuscular function of female rugby sevens players. Previous research in elite women's soccer showed little change in countermovement jump performance following a competitive game despite declines in Yo-Yo IR1 performance and repeat sprint ability (114). Potentially, as women appear to exhibit less neuromuscular fatigue than men (7, 183), they may require different recovery strategies to those employed by male athletes following rugby sevens tournaments.

Muscle damage

Muscle damage can be measured indirectly through a number of blood markers. Within football codes, creatine kinase (CK) is commonly used as a marker of muscle damage. One game of men's rugby sevens does not elicit an immediate increase in CK, however, four hours later an 18% increase was evident, which is further elevated (40%) following a second game (179). Figure 2.3 shows changes in CK following men's rugby sevens games and after a tournament, compared with following a game of rugby union and rugby league. Following day one of a rugby sevens tournament (three games) a similar rise in CK (300 – 500%) occurs compared with a single game of rugby union or rugby league (128, 179, 180). In rugby union and rugby league, CK continues increasing up to 24 hours post game, and remains elevated for up to 48 hours (128, 180). By the end of a rugby sevens two-day tournament, CK concentrations are similar to those reported 24 hours post game in rugby union and rugby league (128, 179, 180). Likely, CK levels continue to rise above currently reported values in rugby sevens for up to 24 hours post tournament, similar to the delayed effects reported in rugby union and rugby league players. No research is currently available quantifying changes in CK in the days immediately following a men's rugby sevens tournament. However, one week post-tournament, CK concentrations are known to have returned to baseline levels (204).

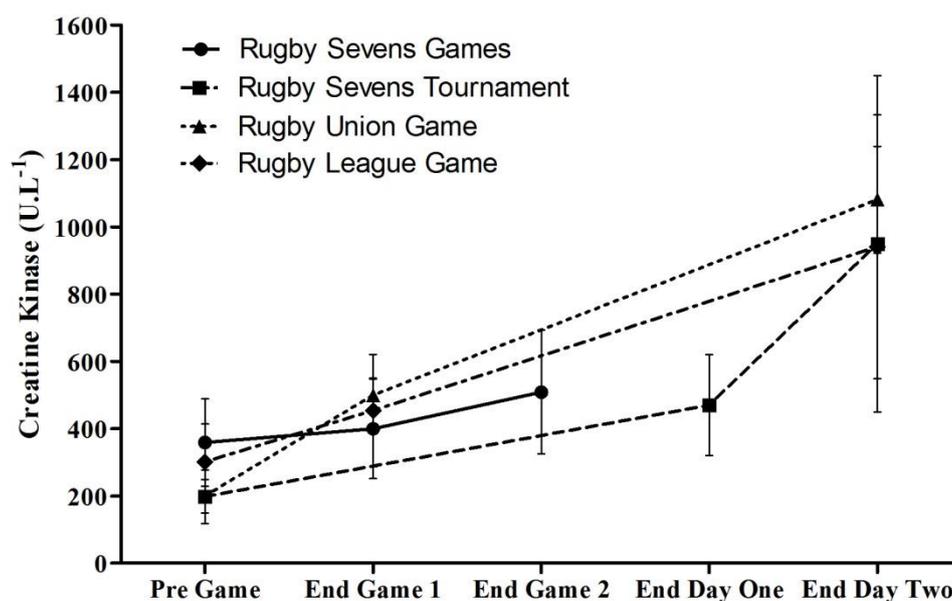


Figure 2.3. Creatine kinase (CK) response following games or a tournament in rugby sevens (179, 203), rugby union (180) and rugby league (128). Data are presented as mean \pm SD. Bloods were collected within 30 min of games finishing. End Day One includes three games of rugby sevens, End Day Two equates to three games of rugby sevens plus the cumulative effect of the previous day's three games. End Day Two results for rugby union and rugby league game equates to CK measures obtained 24 hours post game.

In rugby league and rugby union large to very large positive correlations are apparent between muscle damage markers and game performance. Increases in CK concentration post-game has a large positive correlation with the number of tackles ($r = 0.92$) (180), time spent defending ($r = 0.73$) and total playing time ($r = 0.69 - 0.82$) (169) in rugby union players. In rugby league, the number of impacts above 7 g-forces largely correlate ($r = 0.63$) with CK concentration post-game (128). While one study showed positional differences following a game of rugby union ($\Delta\text{CK } 540 \pm 340 \text{ U.L}^{-1}$ backs; $1440 \pm 680 \text{ U.L}^{-1}$ forwards), in rugby league no positional differences are apparent despite substantially greater physical contacts for forwards (128, 188). In soccer and Australian Football, where physical contacts are substantially less compared with rugby union and rugby league, CK concentrations post games had large positive correlations with high intensity running and sprinting distances (184, 208). As CK concentration increases from both metabolic and mechanical demands,, muscle damage in rugby sevens is likely related to the cumulative effect of both high

intensity running demands and physical collisions. No research is currently available on the occurrence of muscle damage in women's rugby sevens. Females appear to have lower circulating levels of CK both at rest and following aerobic and eccentric exercise due to a protective effect of oestrogen (28, 135), and so the extent of muscle damage during and after a rugby sevens tournament, as well as the recovery time required post-tournament, may be different between sexes. Furthermore, positional differences in CK concentration and the link to game movements or physical collisions have yet to be reported in men's and women's rugby sevens.

Inflammation

An inflammatory response can occur following acute exercise, as observed by an increase in cytokines, c-reactive proteins, and leukocytes mobilised within the bloodstream. Leukocytes (white blood cells) are the most commonly measured variable of inflammation and can be quantified using standard haematological testing. During the inflammatory process, neutrophils are the first type of leukocyte to appear at the site of trauma or damage. In rugby union, the increase in neutrophil count following a competitive game largely correlates with the number of contacts and tackles players are involved in (39). In rugby sevens, while one game is not enough to elicit an inflammatory response, following a second game played four hours later, a substantial response is present (179). The direction of change in reactive oxygen species and phagocytic activity following two games of rugby sevens is similar to that induced by strenuous endurance loading, such as a marathon (179), and implies a cumulative effect is likely with multiple rugby sevens games. Currently, no research is available on the time course and extent of inflammation that occurs following a rugby sevens tournament for men or women. This information could help coaches and support staff implement more specific training sessions to acclimatise players to the demands of competition, introduce more specialised recovery sessions to promote quicker recovery, and minimise the risk of illness and injury post-tournament.

Recovery Interventions

Given the need for rugby sevens players to repeat performances during multiple games over consecutive days, effective game-day and post-tournament recovery strategies are required. Sleep and good nutrition are advantageous for recovery (54), while other interventions such

as CWI, compression garments, stretching and/or massage may also be of benefit. Despite understanding the importance and possible influence of recovery strategies on performance outcomes, little research is available on the most appropriate recovery interventions for rugby sevens. Only one study has examined the use of CWI to attenuate possible reductions in performance in men's rugby sevens (47). Unfortunately, only recreationally-trained male athletes from a combination of rugby sevens, rugby union and rugby league backgrounds were used for this study using a simulated rugby sevens tournament. While the post-game lactate values were substantially lower ($6.9 - 9.4 \text{ mmol.L}^{-1}$, range over six games) than previously reported following an international men's rugby sevens game ($11.2 \pm 1.4 \text{ mmol.L}^{-1}$) (82), a 5 min CWI protocol following each game facilitated cardiac parasympathetic reactivation by maintaining higher heart rate variability (47). Similarly, while repeat sprint performance was similar between CWI and passive recovery options, mean and peak heart rates were better maintained, while the blood lactate response was lower, with CWI (47). Further research is required in this area to observe the most appropriate between-games and between-days recovery protocols that are easy to administer, accessible and/or transportable given the extensive travel associated with rugby sevens tournaments. Applied research in post-game recovery using elite male and female players has yet to be undertaken.

Training monitoring

Questionnaires

Combined with monitoring the external running demands (using GPS) of players, measures of internal training load are frequently obtained from players. The simplest method of measuring internal training load and players' response to training is use of self-reported questionnaires. Rating of perceived exertion (RPE) is commonly used in field sports to provide an internal response to specific training sessions (121). Sessional RPE following training can be used to compare the perceived effort of players with the expected or desired aims of the coach for each session. Quantifying overall player load is achieved by combining both internal and external responses (session duration or distance multiplied by session RPE). These metrics indicate which players are not responding well or may be becoming ill or overtrained. Other questionnaires provide information on general feelings of wellbeing, recovery, and soreness (107), and are highly suitable due to their ease of administration and portable nature. In men's rugby sevens, both a fatigue questionnaire

(57) and a burnout questionnaire (172) have been applied during intensified training programs. Using a fatigue questionnaire that included items regarding perception of training, sleep, infection, soreness, anxiety, irritability and stress, increases in training loads, measured as session duration times RPE, was used to infer increased perceptions of fatigue (57). However, a questionnaire on burnout failed to correlate with self-reported measures with training intensity or player aerobic fitness (172). The burnout questionnaire was used in amateur rugby sevens players, and the demands of training sessions were likely not hard enough to elicit an overreaching response. In Australian Football, as training is reduced leading up to a game perceptual measures of well-being improve (76). Similarly, a bye week was associated with improved perceived fatigue, strain and sleep quality (76). The use of questionnaires can provide a rapid and simple representation of how athletes are responding to training demands, and can be used to adjust subsequent training sessions based on actual versus perceived effort of players to limit under- or over-training.

Hormones

Another method to assess players' physiological response to training demands is through the hormonal response of testosterone and cortisol. These hormones indicate the anabolic and catabolic states of players associated with periods of overreaching and overtraining (111, 193). However, the methods used (salivary or venous blood) to collect this data are both labour intensive and relatively expensive, making it impractical to collect on a weekly basis for extended periods of time. Consequently, only a few studies have quantified these variables in rugby sevens and rugby union. In rugby sevens, a 6-week concurrent strength and rugby-specific training block failed to elicit changes in the concentration of testosterone (T), cortisol (C) or the T/C ratio despite improvements in upper and lower body strength characteristics (35). Unfortunately, weekly measures were not obtained and relationships between weekly training load and changes to T and C were not identified (35). Following a single game of elite men's rugby union T decreases while C increases, lowering the T/C ratio post game (58, 204). In the days following, T becomes elevated above baseline, while C is lower, resulting in an anabolic state for players (58). Short term responses of T and C are expected, however, prolonged diminution of T or elevations in C can indicate periods of overtraining (111, 193). Over a rugby union season both T and C increase while the T/C ratio declines slightly, however, there is no clear relationship between these hormonal changes and physical performance (10). Despite the potential

benefits of this information for coaching staff, given the practical difficulties in administering this test, regular monitoring of T and C hormones are limited. Given T has the ability to influence athletic performance and the potential for physiological adaptations (36), and elite level female athletes appear to have twice the baseline T and C of sub-elite female athletes (31), it may be that elite-level female rugby sevens players also have a relatively high concentration of T. However, whether such information would have any influence over talent identification, selection or training potential is unclear. Similarly, other less invasive and more easily administered tests, may provide a comparable picture on how players are responding to training and competition, and limit the need for measurement of T and C.

Neuromuscular function

Similar to neuromuscular function testing immediately following competitive games, a CMJ test can also be used on a daily or weekly basis to monitor players' neuromuscular response to training. In Australian Football, CMJ results are below baseline values for ~60% of a competitive season (32). While a direct link between changes in CMJ measures and training load was not addressed, a small positive correlation between the change in flight time to contraction time and player votes obtained during a competitive Australian Football game two weeks later was observed (32). This outcome suggests that there may be a delayed response in performance following changes in neuromuscular function. In rugby sevens, only one study on male players (78) and one on female players (77) have used CMJ testing to monitor players during extended training periods. Following an elite men's rugby sevens team for three weeks leading into an international competition, there was no improvement in the measure of flight time to contraction time during CMJ testing (78), despite reductions in total running distance, high speed running and tackle counts during training sessions. Leading into competition, training is often reduced to allow for restoration of the neuromuscular system. Potentially, the training performed in this study was not reduced enough, or alternatively, the training prior to this period was not hard enough, to elicit such a change. Without knowing the training loads and neuromuscular performance of players over an extended period of time, it is difficult to interpret these results. On the other hand, a six week intensive training period for female rugby sevens players resulted in substantial decrements in a number of CMJ variables (flight time, peak displacement, time to peak force and force at zero velocity) in parallel with an increase in

training loads and a decrease in perceived wellness (77). Variations in neuromuscular function are thought to result in changes to both the kinetics and kinematics of jumping performance. Quantifying more variables of a CMJ may provide a greater understanding of the effects of training and competition on the neuromuscular system. More research is required in this area to detail relationships between neuromuscular changes and training loads in both male and female rugby sevens players.

Nutrition for health and performance

Competition nutrition

Research on the appropriate nutrition and use of supplements for rugby sevens players is limited. Based on current knowledge of training and game demands in men's rugby sevens, and translating nutritional recommendations for rugby union and rugby league players, general nutritional guidelines for rugby sevens players have been developed by Dziedzic and Higham (54). These recommendations focus on ingestion of carbohydrates and proteins, adequate hydration, and use of selected ergogenic aids, mainly creatine and caffeine, during competition to improve performance (Figure 2.4). Practical considerations surrounding travel and the difficulties of fitting in meals around game times are also important (54). Two studies have observed the effect that Ramadan fasting has on body water status, renal function and serum electrolytes at rest and following a simulated rugby sevens game in male players (186, 187). During Ramadan, dehydration status is negatively affected at rest, however, a rugby sevens game did not yield changes to biochemical, cardiovascular or body water status markers (186, 187). Whether substantial differences would become apparent following consecutive games is uncertain. The potential positive use of supplements to improve performance has only been reported in one study (43). This study is also the only nutrition study to be completed with female rugby sevens players. Caffeine consumption ($1 - 6 \text{ mg}\cdot\text{kg}^{-1}$ body mass) 60 min prior to a game improves muscle power output, relative running distance, and the distance spent at a sprinting velocity during international level games (43). Considerably more research is required to better understand the nutritional requirements of rugby sevens players specifically, and the potential benefits and optimal timing for the use of ergogenic aids during competition.

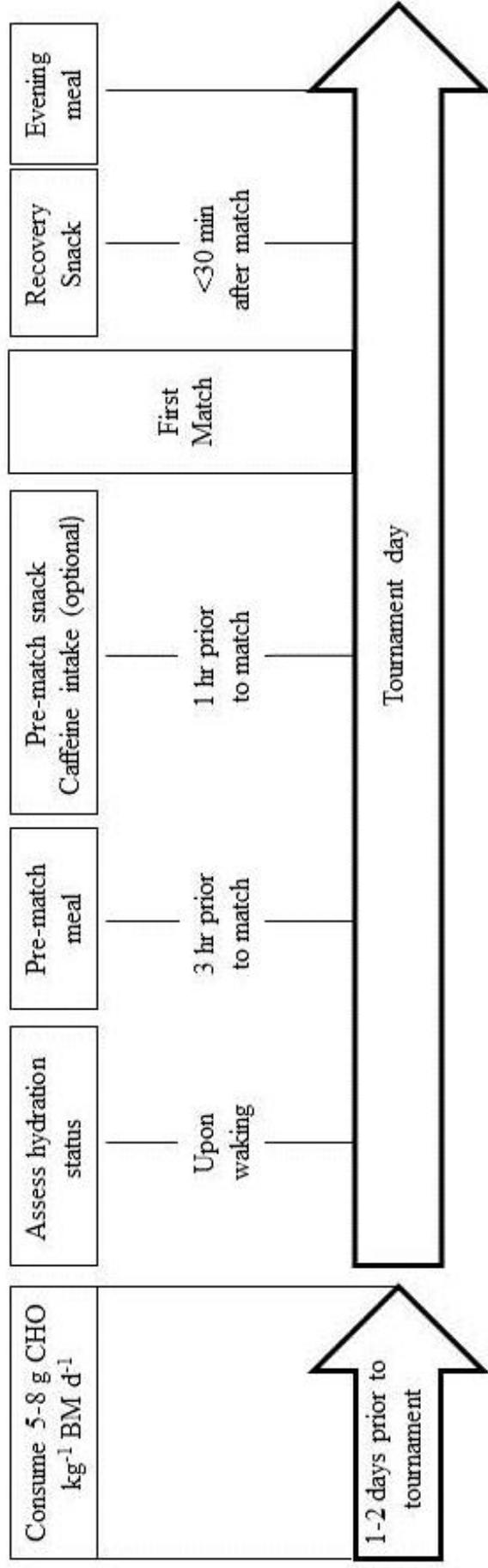


Figure 2.4. Timeline of key nutrition guidelines for a typical tournament schedule. g CHO kg⁻¹ BM d⁻¹: grams of carbohydrate per kilogram of body mass per day. Adapted from Dziedzic and Higham (54).

Nutrition and iron deficiency

One area that may hold specific interest for female rugby sevens players compared with male players is that of iron deficiency. Female athletes can have inadequate intake of dietary iron (110), and, when combined with the high training loads and contact-induced haemolysis resulting from rugby sevens training and competition, the incidence of iron deficiencies may be of concern for female rugby sevens players. In athletes, iron deficiencies occur due to the combined issues of: a loss of iron from the accelerated turnover of red blood cells (haemolysis), increased sweat volume, and urine output (24); reduced iron absorption due to an increase in exercise-mediated hepcidin release (144); and, possibly inadequate dietary iron intake. In female athletes, the dietary requirement for iron is twice that of men (18 mg.day⁻¹; 8 mg.day⁻¹ for males) (22). Endurance-trained female athletes lose a total of ~2.3 mg.day⁻¹ of iron due to menstruation, which is considerably greater than non-athletic females (~1.4 mg.day⁻¹) and endurance trained males (~1.7 mg.day⁻¹) (201). Oral contraception, however, can reduce the amount of blood lost during menses (99, 115) and may indirectly elevate ferritin levels. Given the ability of an iron deficiency to impair players' endurance performance (85), physical capacity to train (44, 96), mental state (20, 112), and ability to recover and adapt (19, 210), monitoring the presence of iron deficiencies in female athletes is worthwhile, as is the potential beneficial use of oral contraceptives.

While quantifying the negative effects of iron deficiency on intermittent team-sport performance is difficult, a substantial number (up to 30%) of both male and female team-sport athletes present with iron deficiency (49, 156). However, little research has been conducted in rugby league and rugby union, and no research is available on rugby sevens players. In men's rugby union, small variations in haemoglobin, haematocrit and ferritin occur throughout a competitive season in response to periods of heavy training and competition (17), however, these changes were of little clinical significance. No research is available on haematological changes that occur throughout a competitive season for female team-sport players. Understanding the incidence rate of iron deficiency in female rugby sevens players may improve the monitoring of athletes, with early detection informing better management of subsequent training and competition performances. Awareness of the link between training and competition loads and the fluctuations in iron stores may also improve the timing of haematological tests for player monitoring.

Summary

A combination of short- and long-term strategies have been used to monitor rugby sevens players, however, further work is warranted. Understanding the time course and magnitude of a decline in neuromuscular function, and degree of muscle damage following rugby sevens games, in addition to how the degree of change are affected by the game movements of players, can potentially improve the prescription of recovery and return to training following tournaments. Little research is currently available on the inflammation that occurs following games, or the implementation of specific recovery interventions, and no research has been conducted on the immediate physiological disturbances following tournaments in female rugby sevens players. Long-term monitoring of players to ensure appropriate training loads with adequate recovery periods has yet to be undertaken in men's and women's rugby sevens. Given the ease of use and portability of questionnaires and CMJ monitoring of neuromuscular function both are likely advantageous over hormonal testing of T and C. Effective nutritional support both during training periods and the competitive season will assist the recovery and adaptation of players. The need for specific consideration of dietary iron intake to reduce the incidence of iron deficiencies in female rugby sevens players is currently unclear and warrants further investigation.

Conclusion

The majority of research currently available in rugby sevens focusses on the running movements and patterns of play during competitive games and tournaments. Mostly, this research is conducted in elite level male players, with limited research also available in provincial level men's rugby sevens and elite women's rugby sevens players. Observing the game movements and physical characteristics of players reveals some variation between playing levels, while small to trivial differences are apparent between playing positions in both the men's and women's game. However, these differences have only been observed in a small number of studies and more research is required to understand the positional and competition level differences in the game demands and physical profiles of men's and women's rugby sevens. More information should aid the appropriate prescription of training, as well as for talent identification and selection purposes. Furthermore, contention remains in regards to the appropriate speed threshold used to define high-intensity running for women, and detection of impacts and collisions using microsensor technology

In addition, little research is currently available documenting the short-term effects of competition and the long-term effect of training on players. Initial studies indicate the muscle damage, neuromuscular fatigue, and inflammation resulting from men's rugby sevens games and tournaments are similar to that experienced in men's rugby union and rugby league. However, no research has observed the degree of muscle damage, fatigue and inflammation that follows a women's rugby sevens tournament. Given the high-intensity and physical nature of rugby sevens training and competition, nutrition also plays an important role in the development and recovery of players. While training and competition places an additional demand on the intake of dietary iron due to increased haemolysis and sweating, knowledge on the presence of iron deficiencies in female contact sport athletes, where menstruation places additional demands on the need for iron, is limited. Awareness of the incidence of iron deficiencies in female rugby sevens players, along with knowledge on how the competitive season and use of an oral contraceptive may influence this, are important for the appropriate management and preparation of players.

CHAPTER THREE

Game movement demands and physical profiles of junior, senior and elite male and female rugby sevens players

Clarke AC., Anson JM., Pyne DB., Game movement demands and physical profiles of junior, senior and elite male and female rugby sevens players, *Journal of Sport Sciences*. Epub ahead of print, May 23; 1-7, 2016.

Abstract

To inform recruitment, selection, training and testing of male and female rugby sevens players game running movement patterns and physical characteristics were quantified across Junior, Senior and Elite playing levels. Anthropometric and physical testing (40 m sprint, vertical jump, Yo-Yo IR1) occurred prior to players' national championships or international tournaments (n=110 players), while game movements were obtained via GPS (n=499 game files). The game movements of male players were similar across playing levels except for number of impacts >10g which were two- to four-fold higher in Elite (25.0 ± 11.2 impacts.game⁻¹; mean \pm SD), than Junior (6.3 ± 3.5) and Senior (11.8 ± 6.6) players. In men, there were fewer substantial correlations between on- and off-field measures which may reflect similar physical attributes across playing levels, and that other (strength, technical or tactical) factors may better differentiate these players. In females, Elite players had more favourable on- and off-field performance measures than Juniors and Seniors, with moderate to strong correlations between on- and off-field variables. Female players should benefit from additional fitness training, while male players need to balance fitness with other technical and tactical factors.

Introduction

Studies in rugby league and rugby union have documented the anthropometric, physical and match demands of athletes at various playing levels (33, 70, 127, 170). This information is useful for player assessment, recruitment, selection, and prescription of training at higher representative levels. Research in men's rugby sevens has characterised players and the game at elite and provincial levels of competition (90, 94, 162, 164, 174) but there is no data available on junior (under 18) male players. In female rugby sevens, the analysis of on- and off-field performance of players is predominantly in elite-level players (25, 27, 175) with some research also comparing elite and provincial players (26, 148, 194).

Previous research in women's rugby sevens shows that international level players complete greater total and high-speed running distances during games compared to development players (194), while elite male rugby sevens players have favourable anthropometric and physical qualities compared to provincial-level players (164). Currently though, there is no data available on the game movements or physical profiles of junior male or female rugby sevens players. In rugby league and soccer, substantial game and physical differences are apparent between junior and senior players (127, 136), with a more pronounced gap in the women's performances (136). Given the potential influence of playing level, and/or fitness to affect subsequent muscle damage and neuromuscular fatigue in players (26) understanding the differences between playing levels is worthwhile. Rugby sevens is a relatively new sport to the world stage, and it is possible that a large gap exists between junior and elite playing levels, especially for female players who anecdotally are coming from a wide array of sporting backgrounds, compared to males who would predominately come from rugby union, or possibly rugby league. Comparing differences between sexes and the development changes across playing levels can help to direct specific training requirements needed as well as gain a greater understanding of the effect that other aspects of the game, such as playing history and training background can influence the physical progression and game movements of players across playing levels.

Anthropometric and physiological characteristics can influence the on-field performance of players in different codes of football. In men's rugby sevens, faster 10 and 40 m sprint times correspond ($r = 0.32 - 0.51$) to a greater number of line breaks, effective tackles made

and defenders beaten during games (163). Similar relationships are evident in men's rugby union (170), rugby league (70) and Australian Football (209). However, understanding whether anthropometric and physiological characteristics influence the running movement patterns of players is unclear. Relationships between anthropometric and physical assessments with game running movements (via global positioning systems, GPS) of rugby sevens players have yet to be established. Similarly, whether playing level or sex affect possible relationships between such measures is also uncertain.

The aim of this study was to quantify the game running movement patterns and the anthropometric and physical characteristics of male and female rugby sevens players across three tiers of playing levels (Junior, Senior and Elite). Relationships between game movements and anthropometric and physical assessments were also quantified.

Methods

Experimental approach to the problem

A cross-sectional study was conducted on rugby sevens players to quantify differences in game playing movements and physical measures between sexes (male and female) and playing level (Junior: <18 yrs, Senior: >18 yrs competing in domestic competitions only, Elite: >18 yrs contracted players competing for Australia in World Series). GPS data were collected during the Australian National Rugby Sevens Championships, a two-day tournament, for Junior and Senior players, and at two international World Series tournaments for Elite players. Physical testing was completed approximately four weeks prior to tournaments.

Subjects

Male and female rugby sevens athletes (n=110) across three playing levels (Junior, Senior, Elite) were involved in this study (Table 3.1). Ethics approval was obtained from the University of Canberra Committee for Ethics in Human Research and the Australian Institute of Sport Ethics Committee. After explanation of the study purposes, benefits and methods, written informed consent was provided by players or their parent/guardian prior to participating.

Procedures

Each tournament was completed over two consecutive days, with three games played each day. Junior and Senior players finished their respective National Championships in the top three places, while Elite players finished the 2014-15 Sevens World Series season in 3rd place (women) and 5th place (men). All on-field game movements were captured using GPS units (5 Hz (interpolated to 15 Hz) SPI HPU, GPSports Systems, Canberra, Australia). These units are considered acceptable for use in team-sports (typical error = <10% for speeds <20 km.h⁻¹, and 19% for speeds >20 km.h⁻¹) (102). For analysis, the half-time interval was excluded. Game files where players were involved in less than seven min of game time were excluded to reduce the possible effect of substitutions (90). Once a player was substituted they did not return to the field that game. As such, the reported GPS data refers to when a player was on the field and the game was in play, irrespective of stoppages due to penalties or tries.

In total, 499 game files were obtained (Junior men n=88, Junior women n=83, Senior men n=68, Senior women n=90, Elite men n=81, Elite women n=89). Game variables analysed include total distance (m), max speed (m.s⁻¹), max acceleration (m.s⁻²), number of impacts >10g (n), relative total distance (m.min⁻¹), total (m) and percent (%) distance covered above 3.5 m.s⁻¹, total (m) and percent (%) distance covered >5 m.s⁻¹, total (m) and percent (%) sprint distance, and mean sprint duration (s). Distance covered above 3.5 m.s⁻¹ are potentially a better measure of ‘high intensity’ for women than the commonly used 5 m.s⁻¹ threshold (25). Sprint distance was determined as the distance covered while accelerating >2.0 m.s⁻² for longer than one sec (90). The use of GPS-derived impacts >10g has not yet been validated, however, was included in this study on the basis of manufacturer recommendations and an earlier study (69).

Physical measures of height, body mass, and sum of seven skinfold sites were collected by the same ISAK-accredited anthropometrist (coefficient of variation (CV) = 3%). Lean mass was calculated as body mass/sum of seven skinfolds^x, where x = 0.17 for women and 0.14 for men (52). Players’ sprinting ability was measured over 40 m, with splits at 10 and 30 m, starting 30 cm behind the start line, using infra-red lightgates (CV = 8%, Fusion Sport, Brisbane, Australia). Players were given three attempts and the best time (and associated splits) reported. The 30-40 m split time was used to calculate max velocity (m.s⁻¹), which was then multiplied by players’ body mass to obtain a measure of momentum (kg m.s⁻¹).

Lower body power was measured via a vertical jump test (CV = 2%, Vertec, Swift Performance Equipment, Queensland, Australia). Players were given three attempts to reach maximal height (best attempt reported). The Yo-Yo IR1 (m) was used as a measure of aerobic fitness (CV = 4.9%) (113), and was completed following all other tests. Some individuals did not complete one or more of the physical tests due to injury or unavailability. Given the large variation in ability across groups, a common strength test was not deemed appropriate for this study.

Statistical Analysis

Descriptive data are presented as mean \pm SD. Raw data were log-transformed prior to analysis using inferential statistics. Data were analysed across playing levels (within sex), between sex (within playing levels), and between playing positions (within playing levels and sex). Standardised mean changes (Cohen's effect size, ES) were used to characterise the magnitude of difference using the following criteria: ES <0.2 trivial; 0.2-0.6 small; 0.6-1.2 moderate; 1.2-2.0 large; 2.0-4.0 very large; >4.0 extremely large (97). Confidence limits (CL) were set with 90% precision of estimation. Differences were deemed unclear if the ES simultaneously crossed the threshold of ± 0.2 . Pearson's Product-Moment correlations were used to assess the relationship between game movement patterns and anthropometric and physical assessments of male and female players across all playing levels combined. Correlations (*r*-values) were interpreted against the following criteria: *r*<0.1 trivial; 0.1-0.3 small; 0.3-0.5 moderate; 0.5-0.7 large; 0.7-0.9 very large; >0.9 almost certain (97). Confidence intervals (CI) were set with 99% precision of estimation. When the CI of effects simultaneously crossed the threshold of ± 0.1 the association was deemed unclear.

Results

Anthropometric Characteristics

The anthropometric characteristics of players are presented in Table 3.1. Across all playing levels male forwards were taller (3-6%, ~ 0.88 , ± 0.66 ; range, ES, $\pm 90\%$ confidence limits), heavier (7-21%, ~ 1.34 , ± 0.85), and had greater lean mass (8-20%, ~ 1.40 , ± 0.95) than backs. Skinfold thickness was similar between positions at each playing level. Female forwards (Junior and Senior) were moderately taller (4-5%, ~ 1.00 , ± 0.64), heavier (20-25%, ~ 1.88 ,

± 0.86), had higher skinfolds (20-40%, ~ 1.28 , ± 0.65) and greater lean mass (16-18%, ~ 1.71 , ± 0.92). At the Elite level, only mass was largely greater in forwards (9%, 1.48, ± 1.38).

Physical Testing Results

Table 3.1 shows the physical testing results of male and female rugby sevens players. Males had better anthropometric and physical testing scores than females within each playing level (ES = 1.83–5.10), except for 10 m sprint time at an Elite level (-0.07 , ± 0.58). Only two Senior male players who completed physical testing identified as a back, and so comparison between playing positions at the Senior level was not possible. Junior and Elite male backs were moderately faster (40 m) than forwards (3%, 0.80, ± 0.83), while Elite forwards also had better Yo-Yo IR1 performance (forwards, 2504 ± 241 m; backs, 2255 ± 419 m). Vertical jump, 10-m sprint and player momentum did not differentiate playing position at either level for men. Junior female backs were substantially fitter, faster and more powerful (ES = 0.89–1.78) but with lower running momentum (2.06, ± 1.10) than forwards. No substantial differences between playing positions were apparent for Senior women, while in Elite women, backs were $\sim 4\%$ faster in 10-m and 40-m sprint times (1.30, ± 0.77).

Table 3.1. Anthropometric characteristics and physical testing results of male and female rugby sevens players at different playing levels. Data presented as mean \pm SD.

	Men			Women		
	Junior (n=22)	Senior (n=18)	Elite (n=13)	Junior (n=24)	Senior (n=22)	Elite (n=11)
<i>Anthropometry</i>						
Height (m)	1.82 \pm 0.08	1.81 \pm 0.05	1.84 \pm 0.07 [†]	1.64 \pm 0.07	1.70 \pm 0.07 [‡]	1.69 \pm 0.02
Mass (kg)	81.9 \pm 7.1	88.5 \pm 10.2 [‡]	92.0 \pm 6.9 [†]	63.6 \pm 11.8	70.4 \pm 9.3 [‡]	68.6 \pm 4.4
Sum7 (mm)	65 \pm 20	56 \pm 13 [†]	48 \pm 6 [†]	115 \pm 28	89 \pm 20 [‡]	67 \pm 14 [§]
LMI (mm.kg ⁻¹⁴)	46.1 \pm 3.7	51.2 \pm 6.2 [§]	53.8 \pm 4.1 [†]	28.4 \pm 4.3	32.9 \pm 3.8 [‡]	33.7 \pm 2.4
<i>Physical Testing</i>						
10 m split (s)	1.67 \pm 0.06	1.72 \pm 0.07 [‡]	1.76 \pm 0.06 [†]	1.88 \pm 0.09	1.82 \pm 0.06 [‡]	1.76 \pm 0.05 [‡]
40 m split (s)	5.18 \pm 0.20	5.21 \pm 0.17	5.14 \pm 0.16 [†]	6.00 \pm 0.28	5.79 \pm 0.17 [‡]	5.50 \pm 0.16 [§]
30-40 m split (s)	1.13 \pm 0.06	1.11 \pm 0.02 [†]	1.10 \pm 0.04	1.36 \pm 0.08	1.29 \pm 0.04 [‡]	1.22 \pm 0.05 [§]
Final Velocity (m.s ⁻¹)	8.88 \pm 0.48	9.03 \pm 0.17 [†]	9.13 \pm 0.32	7.39 \pm 0.41	7.77 \pm 0.26 [‡]	8.23 \pm 0.34 [§]
Initial Momentum (kg m.s ⁻¹)	492 \pm 49	512 \pm 62	523 \pm 46	341 \pm 52	393 \pm 47 [‡]	390 \pm 27
Final Momentum (kg m.s ⁻¹)	730 \pm 67	800 \pm 97 [‡]	840 \pm 62	474 \pm 71	556 \pm 75 [‡]	565 \pm 42
Vertical Jump (cm)	62.2 \pm 9.7	60.3 \pm 6.1	65.8 \pm 9.3 [‡]	43.3 \pm 5.0	47.4 \pm 5.5 [‡]	49.6 \pm 3.8 [†]
Yo-Yo IRI (m)	1645 \pm 362	1895 \pm 423 [‡]	2351 \pm 371 [‡]	836 \pm 323	1058 \pm 249 [‡]	1702 \pm 329 [§]

† small effect size; ‡ moderate effect size; § large effect size; Substantial differences between Junior and Senior players shown in Senior column, differences between Senior and Elite players shown in Elite column. Negative sign present when Junior > Senior, or Senior > Elite players. Sum7, sum of seven skinfold sites; LMI, lean mass index; Yo-Yo IRI, Yo-Yo intermittent recovery test level 1.

Game Movement Patterns

Mean game movement patterns of male and female players are presented in Table 3.2 and Table 3.3, respectively. Within each playing level, game movements of male players were substantially higher than females (~13-60%, ES = 0.43–2.99, small to very large), except for total distance (Senior and Elite level) and relative total distance (Senior level). The greatest differences in each playing level between sexes were distance covered >5 m.s⁻¹, sprint distance and impacts >10g.

Table 3.2. Mean game movement patterns of male rugby sevens players across playing levels. Data presented as mean ± SD.

	Junior (n=22)	Senior (n=18)	Elite (n=14)
Total Distance (m)	1213 ± 221	1176 ± 259	1249 ± 348
Relative Total Distance (m.min ⁻¹)	103 ± 8	101 ± 9	103 ± 9
Max Speed (m.s ⁻¹)	8.51 ± 0.76	8.68 ± 0.56	8.70 ± 0.99
Max Acceleration (m.s ⁻²)	3.64 ± 0.36	3.85 ± 0.47 [†]	4.02 ± 0.50
Impacts >10g (n)	6.3 ± 3.5	11.8 ± 6.6 [‡]	25.0 ± 11.2 [*]
Distance >3.5 m.s ⁻¹ (m)	440 ± 102	439 ± 93	483 ± 172
Distance >3.5 m.s ⁻¹ (%)	36.0 ± 5.2	37.6 ± 6.0	37.7 ± 5.8
Distance >5 m.s ⁻¹ (m)	182 ± 53	189 ± 41	201 ± 79
Distance >5 m.s ⁻¹ (%)	14.9 ± 3.4	16.3 ± 4.6 [†]	15.6 ± 4.2
Sprint Distance (m)	184.3 ± 52.4	224.3 ± 46.1 [‡]	223.2 ± 104.7
Sprint Distance (%)	15.2 ± 3.0	19.3 ± 4.2 [‡]	16.9 ± 4.3 ^l
Mean Sprint Duration (s)	3.9 ± 0.6	3.9 ± 0.9	4.2 ± 1.6

[†] small effect size, Junior < Senior players
[‡] moderate effect size, Junior < Senior players
^l moderate effect size, Senior > Elite players
^{*} large effect size, Senior < Elite players

Positional differences in game movement patterns were most apparent in Junior women compared to any other group. Junior female backs covered greater movements compared to forwards for all GPS measures (7-56%, ES = 0.81–3.06, moderate to very large). Total distance, distance >3.5 m.s⁻¹ and distance >5 m.s⁻¹ were also small to moderately greater in Senior female backs (0.56–1.09), while at an Elite level there were no positional differences. For male players, Junior backs had small to moderately greater max speed, distance >5 m.s⁻¹, sprint distance, and number of impacts >10g (10-20%). Senior male backs obtained a moderately greater number of impacts >10g per game (1.05, ±0.88), while

Elite backs had greater max acceleration (1.38, ± 1.44). No other differences were apparent in male players.

Table 3.3. Mean game movement patterns of female rugby sevens players across playing levels. Data presented as mean \pm SD.

	Junior (n=22)	Senior (n=21)	Elite (n=11)
Total Distance (m)	1060 \pm 318	1099 \pm 228	1078 \pm 197
Relative Total Distance (m.min ⁻¹)	90.9 \pm 8.1	98.2 \pm 12.4 [‡]	85.8 \pm 3.9 ⁻
Max Speed (m.s ⁻¹)	7.08 \pm 0.83	7.40 \pm 0.52 [†]	8.05 \pm 0.55 ^{†+}
Max Acceleration (m.s ⁻²)	3.18 \pm 0.43	3.31 \pm 0.41 [†]	3.49 \pm 0.38 [§]
Impacts >10g (n)	4.9 \pm 2.6	10.2 \pm 7.1 [‡]	12.6 \pm 4.7 [§]
Distance >3.5 m.s ⁻¹ (m)	289 \pm 117	330 \pm 97 [†]	323 \pm 87
Distance >3.5 m.s ⁻¹ (%)	27.0 \pm 6.7	29.8 \pm 5.2 [†]	29.7 \pm 3.4
Distance >5 m.s ⁻¹ (m)	89 \pm 52	102 \pm 44 [†]	120 \pm 41 [§]
Distance >5 m.s ⁻¹ (%)	8.3 \pm 4.2	9.2 \pm 2.9 [†]	11.0 \pm 2.7 [§]
Sprint Distance (m)	93.8 \pm 47.4	126.9 \pm 42.9 [†]	148.6 \pm 39.1 [§]
Sprint Distance (%)	8.9 \pm 4.1	11.6 \pm 3.3 [†]	14.2 \pm 2.8 [§]
Mean Sprint Duration (s)	3.5 \pm 1.0	4.2 \pm 1.7 [†]	4.1 \pm 0.44

† small effect size, Junior < Senior players
‡ moderate effect size, Junior < Senior players
§ small effect size, Senior < Elite players
|| moderate effect size; - Senior > Elite, + Senior < Elite players

Correlation between on- and off-field measures

Correlations between game running movements and Yo-Yo IR1, 10 m sprint and skinfold thickness are presented in Figure 3.1. Relative total distance did not correlate substantially with any measure, except for age in women ($r = 0.32$, -0.04 to 0.60, 99% confidence interval). Overall, there were a greater number of positive correlations between on- and off-field measures for females. Age positively correlated with number of impacts >10g, relative and absolute total distance, sprint distance and max acceleration ($r = 0.27$ – 0.53) in females. Player mass had negative correlations with max speed, max acceleration, total distance and distance >3.5 m.s⁻¹ ($r = \sim 0.33 \pm 0.30$). Sprint time (40 m) negatively correlated with all on-field movements ($r = -0.42$ to -0.71) except was unclear for absolute and relative total distance covered. Vertical jump correlated positively with max speed, sprint distance, distance >5 m.s⁻¹ and impacts >10g ($r = 0.39$ – 0.50). In male players, 40-m sprint time negatively correlated with max speed, max acceleration and distance > 5 m.s⁻¹ ($r = -0.35$ to -0.61) while vertical jump performance correlated positively with max speed and acceleration only ($r = \sim 0.39$, -0.03 to 0.70). Age and LMI moderately correlated with

impacts >10g and sprint distance ($r = \sim 0.40$, 0.09 to 0.72), while player mass and momentum correlated positively with sprint distance ($r = \sim 0.32$, -0.10 to 0.67). No other substantial correlations were observed in male players.

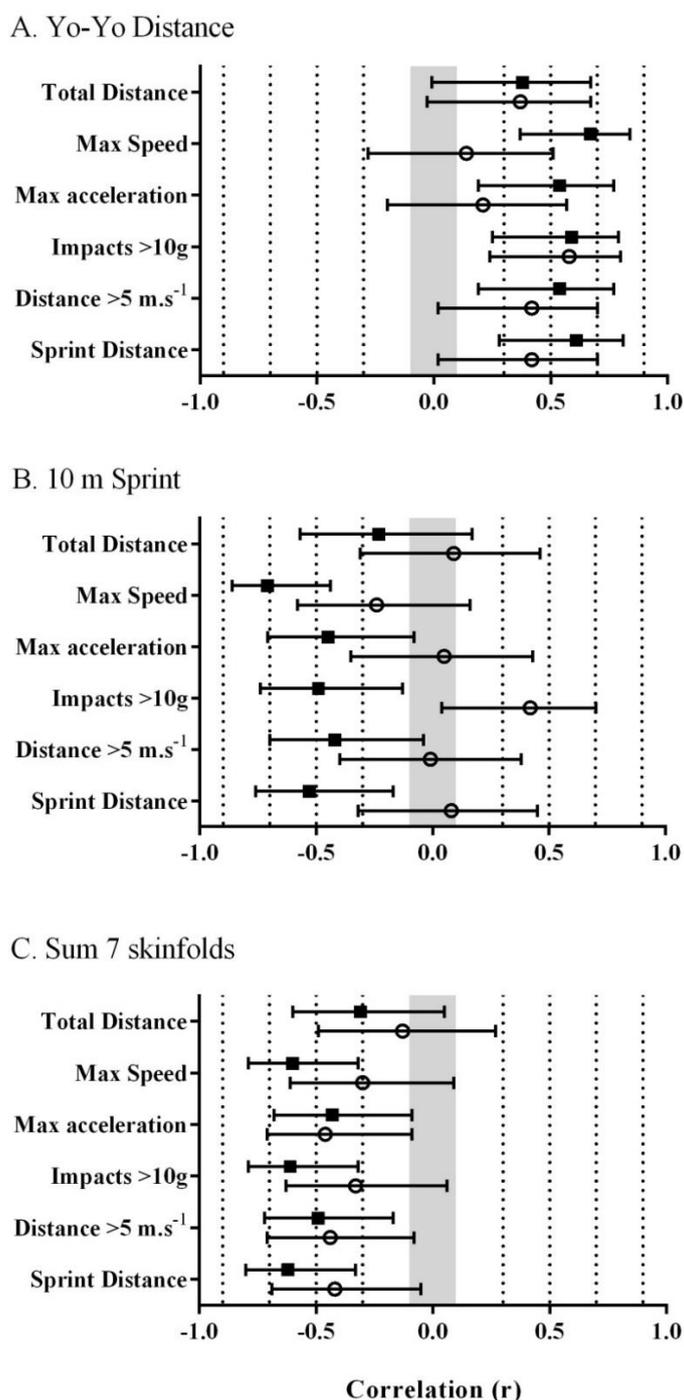


Figure 3.1. Correlation between on-field running measures and A) Yo-Yo distance, B) 10 m sprint time, and C) Sum of seven skinfold thickness, in women (squares) and men (circles). Data presented with 99% confidence interval. Correlations are unclear when they cross over the grey area at ± 0.1 . Dotted lines represent the thresholds for small (0.1-0.3), moderate (0.3-0.5), large (0.5-0.7), very large (0.7-0.9) and almost certain (>0.9).

Discussion

This is the first study to characterise the game movements and anthropometric and physical attributes of male and female rugby sevens players across different playing levels. The number of impacts >10g per game was the main difference in male players across playing groups, likely related to their larger size and more physical style of play. For females, there were moderate to large on- and off-field differences from Junior to Senior and Elite level. Correlational analysis showed that, for females, superior physical fitness is beneficial for on-field performance, while in men it is harder to discriminate playing levels using fitness tests, possibly as a result of greater emphasis on aspects not covered in this study such as strength, power, technical or tactical ability.

Elite female players in this study completed on-field movements slightly below (~30% less total distance, ~14% lower relative total distance, but equivalent % distance >5 m.s⁻¹) previous reports (148, 175). These differences likely reflect match-to-match variation, team tactics, and potential differences in the standard of competition. While considered of National level standard (148, 175) the games reported were not part of the current Women's Sevens World Series, and may not represent the top level competition available to female players. Differences in what is termed an elite-level are likely related to the emerging stage of women's rugby sevens. With time, the evolution of women's rugby sevens will likely see distinct competition standards emerge, making it easier to delineate and differentiate playing levels. Senior female players covered similar game movements compared to another study on senior players (148). No data is currently available on male and female Junior level rugby sevens game movements or physical and anthropometric characteristics. No data exists for the physical and anthropometric characteristics of Senior (non-elite) female players either. In elite females, similar anthropometric and physical results have been reported previously (5, 25, 27, 79). The game movement patterns of male rugby sevens players reported here are similar to data on elite (82, 90, 162) and senior (provincial) level players (173, 178). The physical attributes of elite male players has been well characterised (92, 94, 157, 163, 164), with some studies incorporating players at provincial/national level (163, 164) and report similar outcomes to the current study.

At higher levels of male rugby sevens, the major difference is the greater number of severe impacts (>10g) that players experience. This difference is likely related to the higher total

and lean mass of players at the higher playing levels. However, when comparing positions within each playing level, Junior and Senior backs, who are shorter, lighter and have less lean mass, actually experienced a greater number of impacts >10g. At an elite level, while backs were lighter and leaner than their forward counterparts, a similar number of severe impacts were observed between positions. Backs run at higher speeds before contact and therefore may exhibit higher collision impact ratings (33), however, positional differences in the number of impacts are unclear at elite (95) and provincial (173) men's rugby sevens. In saying this, however, GPS-derived impact ratings are yet to be validated and their reliability in different game and training settings is unclear. Tackle technique, body position running into contact, and team tactics may all play a role in differences observed between teams and individuals. Potentially, at sub-elite levels backs may be more proficient ball players than forwards and simply have more game involvements.

Unexpectedly, total distance, relative total distance and max speed did not differ substantially across playing levels for males despite differences in players' aerobic fitness and sprinting ability. Studies in men's rugby league (127) and Australian Football (192) have successfully differentiated playing level by players' max speed, and total and relative distances covered during games. Although game movements were similar, the Senior and Elite players had moderately greater aerobic fitness (Yo-Yo IR1) and a slower 10 m sprint time. Likely, the greater aerobic fitness of players has a larger effect on maintaining performance following peak work periods within a game, across halves, or between games within a tournament. However, these scenarios were not addressed directly in this study and warrant investigation. Slower 10 m sprint performance, but similar or faster 40-m sprint time at higher playing levels, shows sprinting ability over longer distances likely dominates over short sprint ability in men's rugby sevens given the large amount of space available to players with typical sprint distances of 20-40 m (173, 178). The off-field anthropometric and physical qualities of players reported in this study do not seem to substantially influence the on-field movements of players. However, other measures (not reported) may be of greater importance (e.g. upper and lower body strength and power). Where male players have been involved in rugby-specific training, including strength and conditioning programs, for a number of years, the physical qualities of players are similarly developed and other factors such as technical or tactical proficiency may better discriminate players across playing levels. Understanding the nature and contribution of these other qualities

will promote the development of male rugby sevens players for representative opportunities.

On- and off-field performance measures in female rugby sevens players improve at higher playing levels, while the magnitude of positional differences declines. Presumably, at a young age players are characterised as either a forward or back based on their physical size and speed qualities, however, with elite training, this difference is minimised and other factors such as ball skills, tackling ability and tactical awareness may become the differentiating factors between positions. This scenario is somewhat different to the men where some positional differences remain substantial right up to the elite level, albeit less apparent than at the junior level. These variations may be related to sex differences in game play, as a result of individual team variation in game and training methods, or from the influence of the coach on team selection. Unclear or small differences have been observed between playing positions in women's (5) and men's (82, 95, 173) rugby sevens. Consequently, the need for individualising training based on rugby sevens position remains debateable. Despite the lack of positional differences, the game demands and fitness characteristics documented here for each playing level in women's rugby sevens informs player development for upcoming tournaments and future representative aspirations. Likely, there are other subtleties that discriminate positions in rugby sevens and warrant further assessment to enhance the specialisation of players.

Correlations between fitness tests and game movements in female players show that general athletic ability is beneficial for game performance. In men, however, fewer relationships between on- and off-field measures were apparent. Similar to our study, Mujika et al. (136) reported large correlations between physical tests for female, but not male, soccer players and deemed some tests more appropriate to discriminate female players (e.g. vertical jump) but not males. Given the moderate to large correlations for the majority of on- and off-field measures in female players, those who are generally more athletic will likely perform well in rugby sevens at all levels of competition. For example, female squad players chosen for international representation (and greater game time) had 5-10% better aerobic capacity and strength characteristics than those not selected (79). However, given women's rugby sevens is still a relatively new sport there is likely to be substantial growth and development in this game over the coming years. With the recent inclusion of the Women's World Series, already there has been an increase in the professionalisation of women's rugby sevens in a

number of countries. While it is desirable for players to have well-developed physical attributes, as the game evolves more rugby-specific elements will likely be required for players to progress to higher levels of competition. Differences between the sexes may be a result of the non-specialisation of upcoming female players (or the early specialisation of male players to rugby union/sevens). Other variables which are more rugby-specific (strength/power, tackling ability, tactical awareness) may have a better relationship with game movement patterns and other on-field measures such as line breaks, tackles made and defenders beaten. As women's rugby sevens continues to develop, the requirements of female players to perform successfully will most likely evolve to a combination of fitness and specific rugby-related attributes.

While most game running movements were substantially correlated with at least one anthropometric or physical characteristic, relative running distance ($\text{m}\cdot\text{min}^{-1}$) did not correlate with any measure, nor could it differentiate playing levels for men or women. Provincial and elite-level male rugby sevens players have similar results (90). In rugby sevens, with so much field-space available per player, relative running distance may not be sensitive enough to differentiate standards of play. Instead of observing relative running distance over a whole game, peak relative running distance over shorter game intervals (e.g. a 2 min period) or metabolic power may be used as more discriminating measures (65).

Throughout this study it is assumed that greater game movements result in a more positive outcome for a game. While specific events (e.g. scrum, line out, turnovers) and their effect on point scoring has been quantified in men's rugby sevens (92), understanding whether greater total or high-speed running distances covered is beneficial to a team is yet to be addressed. More successful teams in Australian Football actually perform less high intensity running during games (205). Similarly, female rugby sevens players having comparable game movements to male players is not necessarily desirable either. Given absolute strength and power differences between sexes, a successful performance for one sex may require a different set of skills, techniques and tactics. This has previously been shown in the differences between successful penalty shots in international level men's and women's hockey (134). Coaching staff also have a major influence over the type of player recruited and selected for tournaments, specific skills and physical qualities trained, and the type of game played within all playing levels. Future studies should address measures

of upper and lower body strength as well as objective ratings of tackle technique and tactical decision making, and observe their influence on the on-field performance both through running movements (GPS) and performance metrics (i.e. line breaks, tackles made etc.) in male and female players.

Conclusion

This study provides comprehensive analysis of the match demands of rugby sevens for different playing levels and sexes. These data can be used to prescribe training specific to the demands of competition and develop players for higher representative levels. General physical testing of athletic ability seems appropriate for female players at all playing levels. For male players, physical testing outside of those performed in this study, particularly around strength and power characteristics, as well as measuring technical and tactical ability, may better differentiate players for improving rugby sevens performance.

CHAPTER FOUR

Physiological-based GPS speed zones for evaluating running demands in women’s rugby sevens

Clarke, AC., Anson, J., Pyne, D., Physiologically based GPS speed zones for evaluating running demands in women’s rugby sevens, *Journal of Sport Sciences*. 33: 1101-1108, 2015.

Abstract

High-speed running ($>5 \text{ m}\cdot\text{s}^{-1}$) is commonly reported in men’s rugby union and sevens, however, the appropriateness of using the same speed threshold for women’s rugby sevens players is unclear, and likely underestimates the degree of high-intensity exercise completed by female players. The aim of this study was to establish, for international women’s rugby sevens players, a physiologically-defined threshold - speed at the second ventilatory threshold ($\text{VT}_{2\text{speed}}$) - for the analysis of high-intensity running, using mean and individualised thresholds. Game movement patterns (using 5 Hz GPS) of 12 international women’s rugby sevens players ($23.5 \pm 4.9 \text{ y}$, $1.68 \pm 0.04 \text{ m}$, $68.2 \pm 7.7 \text{ kg}$; mean \pm SD) were collected at an international tournament. Seven of these players also completed a treadmill VO_2 max test to estimate $\text{VT}_{2\text{speed}}$. Compared to the mean $\text{VT}_{2\text{speed}}$ threshold ($3.5 \text{ m}\cdot\text{s}^{-1}$), the industry-used threshold of $5 \text{ m}\cdot\text{s}^{-1}$ underestimated the absolute amount of high-intensity running completed by individual players by up to 30%. Using an individualised threshold, high-intensity running could over- or underestimating high-intensity running by up to 14% compared to the mean $\text{VT}_{2\text{speed}}$ threshold. The use of individualised thresholds provides an accurate individualised assessment of game demands to inform the prescription of training.

Introduction

The use of global positioning systems (GPS) is becoming widespread in many field-based sports. Most notably it is used on a regular basis in football codes such as Australian Football (AFL), rugby union, and rugby league (38). GPS data on players is used to categorise distance and time spent within established speed thresholds, from walking to sprinting efforts (12). GPS data is useful for quantifying the physical game demands of competition, which allow training programs to be sport-specific, as well as for monitoring the sessional exercise dose. Subsequent training and recovery practises for players can then be prescribed, dependant on the observed training load and physical response of individuals. However, GPS is predominately used in male-dominated sports and few studies have examined its use in female team sports. For rugby sevens, both men and women compete at an international level and use GPS monitoring (90, 175), yet it is unknown if the same speed thresholds for the analysis of GPS data is appropriate for both sexes.

While speed zones have been established and are in routine use for male-dominated sports such as rugby league (14), rugby union (40), AFL (132), using the same zones for female athletes may underestimate the physiological demands of activities. For lower intensity activities the typical differences between male and female physiological capacities may not result in any practically significant differences in work rate. At higher intensities and speed thresholds, however, the differences in physiological capacities between sexes, including lower aerobic fitness and absolute sprinting ability in females (136), may lead to substantial differences in physiological cost at a given running speed. Using average velocity distribution curves of movement patterns during games from a range of men's and women's team sports, Dwyer and Gabbett (53) proposed lower speed thresholds for use in women's team sports. Despite this, limited research has applied the use of lower GPS speed thresholds in women's team sports. This study hopes to advance current knowledge by applying physiologically-based reasoning for the use of a lower speed threshold for high-intensity running in female team sports.

In (men's) rugby union, the commonly used threshold which corresponds to high-speed running is $5 \text{ m}\cdot\text{s}^{-1}$. This threshold ($5 \text{ m}\cdot\text{s}^{-1}$) is also used in rugby league (14), and is higher than that used in AFL ($4.2 \text{ m}\cdot\text{s}^{-1}$) (132). The speed threshold of $5 \text{ m}\cdot\text{s}^{-1}$ used in rugby union

was not originally based on a physiological measure but simply (and seemingly arbitrarily) adopted as indicative of 'high-intensity' running (38). As rugby sevens is a short form of rugby union, the same high-speed threshold of $5 \text{ m}\cdot\text{s}^{-1}$ is used for the analysis of GPS data from male players (90, 173). Unlike rugby union, rugby league, and AFL, however, rugby sevens is the only sport to have a consistent international season for women, with regular GPS monitoring of both male and female players. Until now, a potential sex-specific threshold for the regular monitoring of female athletes in rugby sevens has not been explored.

Use of the second ventilatory threshold (VT_2) from a maximal aerobic capacity running ($\text{VO}_2 \text{ max}$) test is one way to physiologically define a threshold point for high-intensity exercise. The VT_2 corresponds to the point where carbon dioxide production exceeds oxygen consumption during exercise (42). On the field, exercise below this threshold can presumably be sustained for an extended period of time, whereas the amount of exercise that can be completed above this threshold is physiologically limited due to non-steady state conditions (42). The speed at VT_2 ($\text{VT}_{2\text{speed}}$) has previously been used in male soccer players (4) and resulted in a 24% lower threshold for high-intensity running compared to the default speed of $19.8 \text{ km}\cdot\text{h}^{-1}$ ($5.5 \text{ m}\cdot\text{s}^{-1}$) using semi-automated player tracking software (ProZone®). This difference in speed thresholds resulted in a 167% increase in the amount of high-speed running that players performed during games (4). Use of $\text{VT}_{2\text{speed}}$ for the determination of high-intensity running is also beneficial as it allows for player individualisation. In a case study by Lovell & Abt (120), individualised $\text{VT}_{2\text{speed}}$ were compared with an arbitrarily set speed of $14.4 \text{ km}\cdot\text{h}^{-1}$ ($4.0 \text{ m}\cdot\text{s}^{-1}$) and while there was a mean overestimation of 9% for high-intensity running when using the arbitrary threshold, individual cases varied by 20-30% either as an under- or overestimation. Consequently, a substantial underestimation (or possibly overestimation) of high-intensity running performed by the players can occur when an arbitrarily-set high-speed threshold is used instead of a physiologically-defined threshold. Also, using individualised $\text{VT}_{2\text{speed}}$ could be a better indicator of the physiologically-demanding (high-intensity) running performed by players when analysing games and training sessions via GPS. In women's rugby sevens, running speeds captured by GPS above players' $\text{VT}_{2\text{speed}}$ threshold may more accurately define 'high-intensity' running, indicative of the demanding work performed by players, rather than just a measure of 'high-speed' running.

While some researchers have used individualised physiologically-defined thresholds for high-intensity running in rugby union (41), these are yet to be widely adopted within the sport. The use of individualised thresholds permits a more accurate prescription of training programs and further understanding of the game as they relate to the specific physiological demands of individual players. While current GPS analysis software has the capacity to analyse data using players' individualised thresholds, there is limited research in this area (38).

The aim of this study was to establish, for international women's rugby sevens players, a mean physiologically-defined threshold (VT_{2speed}) for the analysis of high-intensity running data captured by GPS units throughout a tournament. Further, analysis of game movement patterns using individualised speed thresholds for high-intensity running, as well as the industry-used threshold of $5 \text{ m}\cdot\text{s}^{-1}$ were also explored in relation to players' aerobic fitness and speed capacity.

Methods

Participants

A single cohort, cross-sectional study was conducted on 12 Women's Rugby Seven's players from the Australian National team at the beginning of the 2013-14 international competitive season. The age and physical characteristics of the players were: age 23.5 ± 4.9 y, height 1.68 ± 0.04 m, mass 68.2 ± 7.7 kg, sum of seven skinfolds 75.0 ± 10.7 mm; mean \pm SD). Seven of these players also completed a laboratory-based treadmill maximal aerobic capacity (VO_2 max) test (22.4 ± 2.5 y, 1.69 ± 0.04 m, 68.5 ± 6.9 kg, 72.4 ± 11.5 mm) three weeks prior to the tournament. Written informed consent was obtained from all players following an explanation of the purpose, methodology, benefits and risks of the study and an opportunity to ask questions. This study was approved by both the University of Canberra Human Research Ethics Committee (approval number 13-133) and the Australian Institute of Sport Ethics Committee (approval number 20130804).

Physiological Testing

Laboratory treadmill VO_2 max testing was performed on a custom-built motorised treadmill (Australian Institute of Sport) which comprised a submaximal phase followed by incremental running to volitional exhaustion. Players completed 3-5 x 4 min submaximal

stages starting at 9 km.h⁻¹ (0% gradient). Each subsequent stage was separated by 2 min recovery and increased in velocity by 1 km.h⁻¹. A 5 µL capillary blood sample was taken from the fingertip immediately after each stage and analysed for blood lactate concentration. Players completed a minimum of three submaximal stages and continued until they reached a lactate concentration of 4 mM. A 5 min recovery period was then provided before the commencement of the incremental stage. The incremental stage began at 9 km.h⁻¹ (0% gradient) and increased by 0.5 km.h⁻¹ every 30 s until the speed during the last submaximal stage was reached. At this point, speed remained constant while gradient increased by 0.5% every 30 s until volitional exhaustion.

Heart rate and minute ventilation were recorded continuously during both stages of the test and capillary blood lactate concentration was measured 3 min following completion of the incremental stage. Gas analysis was performed using an in-house (Australian Institute of Sport) built metabolic cart utilising Ametek analysers, a CD-3A carbon dioxide analyser and a S-3A oxygen analyser. A player's VT_{2speed} (m.s⁻¹), velocity at VO₂ max (vVO₂ max; m.s⁻¹) and relative VO₂ max (mL.kg⁻¹.min⁻¹) were obtained from this test. The criteria for reaching VO₂ max comprised a plateau in O₂ uptake (<0.50 litres difference in O₂ between consecutive measurements) or a respiratory exchange ratio ≥1.10 (11). VT₂ was defined at the point where there is an increase in the ventilatory equivalent for both oxygen and carbon dioxide and a decrease in end-tidal partial pressure of carbon dioxide (42). Players' VT_{2speed} and vVO₂ were determined by adopting Saunders et al. (166) method for use with female rugby players. Interpolation of players' VO₂ kinetics from the submaximal stage was used to obtain the corresponding (equivalent) speed at each threshold. The treadmill was calibrated at the start of each day and the gas analysers were calibrated before each test. The coefficient of variation for VO₂ max determination with this protocol in the laboratory is 2.6%.

Game Analysis

Movement data was collected on all 12 players using GPS units (SPI HPU, GPSports Systems, Australia) recording at 5 Hz (interpolated to 15 Hz) during the first round of the 2013-14 Women's Seven's World Series, held in Dubai, United Arab Emirates (28-31°C, 40-50% relative humidity). Similar units are considered valid and reliable for use within a team-sport setting (38). The GPS unit was positioned between the scapulae using a specialised pocket sewn into the playing jerseys. The half-time interval was excluded from

analysis. The team competed in six games over the course of the tournament, which resulted in a total of 68 game files. Forty one game files were from those players who had completed the VO₂ max test previously.

The distance covered at high-intensity was analysed in three ways using the industry-wide threshold for male rugby union (5 m.s⁻¹), players' individual VT_{2speed}, and the group mean VT_{2speed}. The distance covered at low-speed running (<2 m.s⁻¹) and moderate-speed running (2 m.s⁻¹ – individual VT_{2speed}) were also determined, along with players' sprint distance. Sprint distance is reported as the total distance covered during a game where the player is accelerating at >2.5 m.s⁻² for a minimum of one second. Maximum game speed for each player was also recorded, represented by the fastest speed reached over the six games played. Distances covered within each threshold are reported as a percentage of the total distance covered to account for differences in playing times between players.

Statistical Analysis

Descriptive data are presented as the mean and standard deviation (SD). All raw data were log-transformed for heterogeneity prior to analysis using inferential statistics. Data were analysed for both within- (movement patterns averaged per player) and between- (movement patterns averaged per game) player comparisons. Associations between game movement patterns, laboratory VO₂ max test data, and the three speed zone thresholds used (5 m.s⁻¹, mean VT_{2speed} and individual VT_{2speed}) were determined by a Pearson's Product Moment correlation and interpreted against the following criteria: r<0.1 trivial; 0.1-0.3 small; 0.3-0.5 moderate; 0.5-0.7 large; 0.7-0.9 very large; and >0.9 almost certain. Precision of estimation was indicated with 90% confidence limits (97). When a confidence interval ranged from both substantially positive (> 0.1) to substantially negative (> -0.1) the association was deemed unclear (97).

Results

Player physiology and movement patterns

Players had a mean VO₂ max of 51 ± 4 mL.kg⁻¹.min⁻¹, and vVO₂ max of 4.1 ± 0.6 m.s⁻¹ (n=7; mean ± SD). The mean VT_{2speed} was 3.5 ± 0.3 m.s⁻¹ (ranging from 3.2 – 4.1 m.s⁻¹). The mean game movement patterns for all players are displayed in Table 4.1. Omitting the Cup Final due to the greater playing duration, the mean distance ran during games was

1066 ± 89 m and the relative distance was 105 ± 4.9 m.min⁻¹. Players covered on average 37% ± 6% of total distance at speeds above 3.5 m.s⁻¹ and 14% ± 3% above 5 m.s⁻¹.

Table 4.1. Team movement patterns per women's rugby sevens game in an international tournament (n=12 players, *n=7 using individualised VT₂ threshold). Data shown as mean ± SD.

	Total Game Distance (m)	Relative Distance (m.min ⁻¹)	*Distance >ind VT ₂ (%)	Distance > 3.5 m.s ⁻¹ (%)	Distance > 5 m.s ⁻¹ (%)
Game 1	1120 ± 424	108 ± 7	35 ± 5	34 ± 5	13 ± 6
Game 2	916 ± 463	116 ± 18	35 ± 6	36 ± 10	13 ± 8
Game 3	1070 ± 590	107 ± 19	35 ± 7	36 ± 8	13 ± 5
Quarter Final	1140 ± 681	94 ± 11	36 ± 6	33 ± 9	11 ± 5
Semi Final	1080 ± 538	103 ± 17	37 ± 9	39 ± 9	15 ± 5
Cup Final	1660 ± 819	109 ± 16	38 ± 9	38 ± 5	15 ± 5

High-speed running thresholds

The percent distance covered at high-intensity running, using the individualised VT_{2speed}, had a large negative correlation with players’ individual VT_{2speed} (r = -0.62, -0.93 to 0.01, 90% confidence interval). In other words, the higher the threshold speed, the less high-intensity running performed. In contrast, the maximum speed reached during games had a large positive correlation with distances covered above the individualised threshold (r = 0.69, 0.03 to 0.93) (Figure 4.1). The industry-used threshold of 5 m.s⁻¹ yielded high-intensity running distances that correlated very largely with players’ maximum game running speed (r = 0.74, 0.12 to 0.93), but had unclear relationships with VT_{2speed} and vVO₂ max. Using the group mean VT_{2speed} of 3.5 m.s⁻¹, distances covered above this threshold were largely positively correlated with the vVO₂ max of players (r = 0.67, -0.02 to 0.93) only (Figure 4.1).

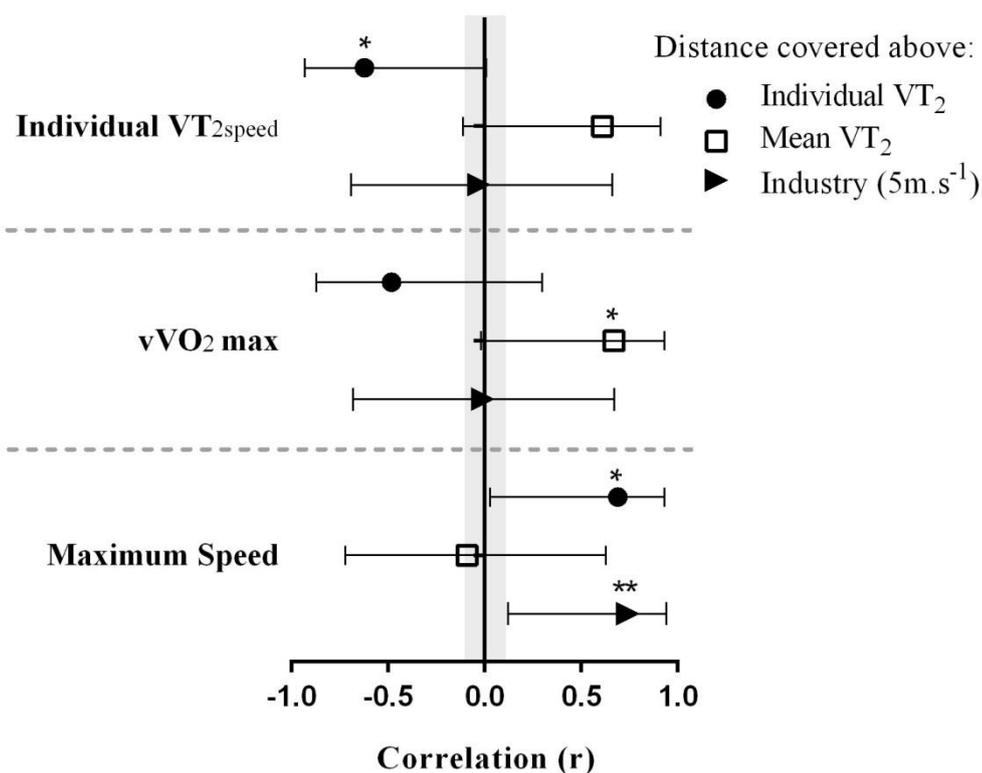


Figure 4.1. Correlations between treadmill VO₂ max variables, maximum game speed, and percent distance covered at high intensity using various speed thresholds for international-level women’s rugby sevens players. Represented as an r -value with 90% confidence interval shown, $n=7$. Shaded area is at ± 0.1 , lines that cross this threshold in both directions are deemed unclear. * large correlation; ** very large correlation.

Player movement patterns and aerobic capacity

Figure 4.2 shows a schematic view of the different speed thresholds used for low-, moderate- and high-intensity running superimposed with players’ individual VT_{2speed}. Variables of players’ aerobic capacity relating to on-field movement patterns are shown in Figure 4.3. Players’ individual VT_{2speed} ($r = -0.72, -0.94$ to -0.08) and vVO₂ max ($r = -0.79, -0.96$ to -0.24) had a very large negative correlation with the percent distance covered at low-speed running ($< 2 \text{ m}\cdot\text{s}^{-1}$). When using players’ individual VT_{2speed} as the threshold between moderate- and high-intensity running, distance covered at moderate speeds ($2 \text{ m}\cdot\text{s}^{-1} - \text{players’ individual VT}_{2\text{speed}}$) had a very large positive correlation with players’ individual VT_{2speed} ($r = 0.81, 0.29$ to 0.96) and vVO₂ max ($r = 0.72, 0.09$ to 0.94) while

high-speed running negatively correlated with players’ VT_{2speed} ($r = -0.62, -0.93$ to 0.01) only.

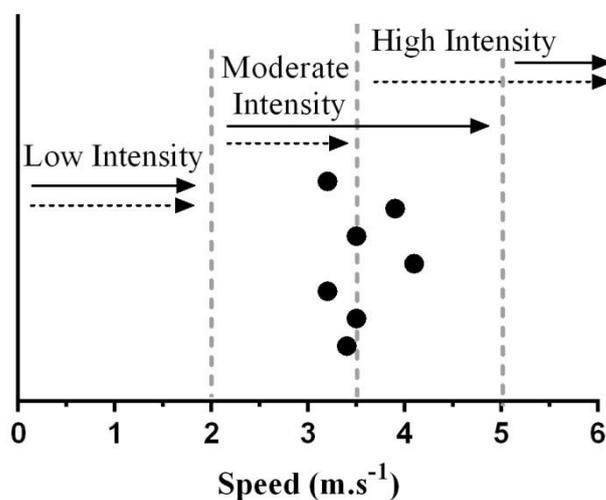


Figure 4.2. Schematic view of speed zone thresholds for low-, moderate- and high-intensity running using GPS, and the effect that a mean physiologically-defined (3.5 m.s^{-1} , represented by the dotted-lined arrows), relative to the industry used (5 m.s^{-1} , represented by the solid-lined arrows) threshold has on intensity determination. Solid circles represent the VT_{2speed} of the seven individual players who completed a VO_2 max test.

Across the tournament, the within-subject between-game analysis showed a moderate positive correlation ($r = 0.55; 0.07$ to 0.82) between the distances covered at speeds above the 3.5 m.s^{-1} threshold and above 5.0 m.s^{-1} . A very large correlation between distances covered above 3.5 m.s^{-1} and above 5.0 m.s^{-1} ($r = 0.89; 0.43$ to 0.98) was apparent during between-subject within-game analysis.

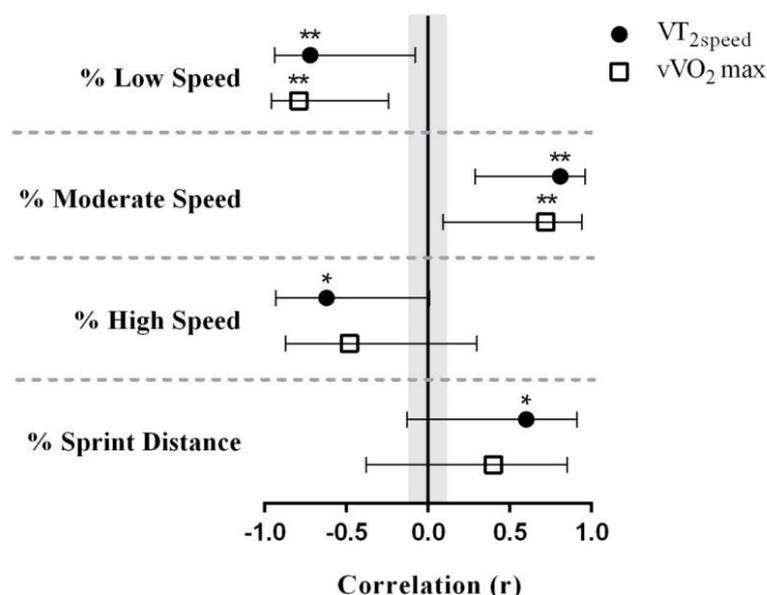


Figure 4.3. Correlation between player fitness variables and percent time spent at Low speed ($<2 \text{ m}\cdot\text{s}^{-1}$), Moderate speed ($2 \text{ m}\cdot\text{s}^{-1}$ to $\text{indVT}_{2\text{speed}}$), High speed ($>\text{indVT}_{2\text{speed}}$), and Sprint Distance (accelerating $>2.5 \text{ m}\cdot\text{s}^{-2}$ for $>1 \text{ s}$). Represented as an r value with 90% confidence interval shown, $n=7$. Shaded area is at ± 0.1 , lines that cross this threshold in both directions are deemed unclear. * large correlation; ** very large correlation.

Discussion

This study shows that use of individualised physiologically-based thresholds for quantifying high-intensity running in women’s rugby sevens players may be superior to a fixed threshold applied across a group. Distances covered above an individually-defined threshold for high-intensity running correlated substantially with both players’ aerobic fitness and high-speed running capacity. In contrast, distances covered by female players above the industry-used (men’s) threshold of $5 \text{ m}\cdot\text{s}^{-1}$ correlated with maximum running speed only. Use of $5 \text{ m}\cdot\text{s}^{-1}$ as the threshold for high-intensity running also underestimated the mean amount of physiologically demanding work that is performed by players during games. While the group mean for the physiologically-defined threshold correlated with players’ aerobic fitness, it did not yield the same direction of association (outcome) to when the threshold was individually applied. However, the mean threshold of $3.5 \text{ m}\cdot\text{s}^{-1}$ may be a practical alternative compared to the currently used threshold of $5 \text{ m}\cdot\text{s}^{-1}$ when player individualisation is not possible.

The use of the VT_{2speed} (both mean and individual) obtained from a treadmill VO_2 max test yields a high-intensity speed threshold in women that is substantially lower than what is currently used for GPS analysis in men's rugby union. The mean VT_{2speed} of $3.5 \text{ m}\cdot\text{s}^{-1}$ in international female players is 30% slower than the currently used threshold of $5 \text{ m}\cdot\text{s}^{-1}$ for high-speed running used in GPS analysis of Men's Rugby Sevens games. High-intensity running occurring above $5 \text{ m}\cdot\text{s}^{-1}$ in this study is similar to other reports in international women's rugby sevens players (143, 207), but greater than reported for domestic-level women's rugby sevens players (9% of total distance $>5 \text{ m}\cdot\text{s}^{-1}$) (175). Previous research adapting speed zones for female players has obtained a similar speed threshold for high-intensity running ($3.4 - 3.7 \text{ m}\cdot\text{s}^{-1}$) using a method based on mean velocity distribution curves in women's hockey and soccer (53). Results of this study also confirm previous research where VT_{2speed} occurs at 86% of a players' vVO_2 max (30). Studies using VT_{2speed} to individualise high-intensity running in men's professional soccer also report lower speed thresholds than arbitrarily-set thresholds (4, 120). However, both of these estimates (in males) are substantially higher than the mean threshold obtained in this study for female rugby players. Clearly, the physiological differences between male and female athletes should be accounted for when establishing high-speed running thresholds for use in team sports.

Using both the mean and individualised VT_{2speed} thresholds resulted in similar mean distances covered at high-intensity while the industry-used threshold of $5 \text{ m}\cdot\text{s}^{-1}$ was much lower (36%, 37%, and 14% respectively). Therefore, use of the fixed threshold of $5 \text{ m}\cdot\text{s}^{-1}$ likely underestimates the mean proportion of high-speed running performed during games by ~20%. However, when examining the effect on individual players, the estimated distance covered at high intensity when using the industry-used threshold of $5 \text{ m}\cdot\text{s}^{-1}$ can underestimate the running demands by up to 30% compared with distance covered using the mean VT_{2speed} threshold. Similarly, using the individualised VT_{2speed} threshold compared with the mean VT_{2speed} , up to 14% of the amount of high-intensity running performed could be over- or underestimated. Such individualised differences in estimates of running demands have been shown previously (120).

Interestingly, players' VT_{2speed} had a negative relationship with distance covered at low- and high-speed (using individualised VT_{2speed} threshold), while there was a positive correlation with distance covered at moderate speeds. This pattern of relationships

demonstrates that players who have a good aerobic running capacity (that is, a higher VT_{2speed} and vVO_2 max) can spend a large proportion of their game at an aerobically-sustainable speed, and consequently do not spend an excessive amount of time above their physiologically-defined high-intensity threshold. Previous research shows that exercise completed above an athlete's VT_2 cannot be sustained for an extended period of time due to the non-steady state nature of the exercise (42). The inverse relationship between high-intensity running and aerobic fitness (VT_{2speed}) in women's rugby sevens players is also apparent in professional male soccer players ($r = -0.68$) when using VT_{2speed} as the high-speed running threshold derived from GPS analysis (4). Similar observations have also been seen in AFL, where the top four teams perform less high-intensity work during games compared to the bottom four ranked teams (205). The ability of players to be able to run a large proportion of the game below this physiologically-defined threshold for high-intensity running is seemingly beneficial for extending the total amount of work that can be performed by players in women's rugby sevens.

When using a fixed mean speed for high-intensity running, however, this relationship is no longer apparent, and instead is reversed. Defining high-intensity running using the group mean VT_{2speed} resulted in a large positive correlation between distance covered at high-intensity and players' vVO_2 max, opposite to that observed when using individual thresholds. This unexpected result probably reflects that for the more aerobically fit players, $3.5 \text{ m}\cdot\text{s}^{-1}$ underestimates the true threshold for physiologically-taxing exercise, and so they can presumably complete a substantial amount of running between $3.5 \text{ m}\cdot\text{s}^{-1}$ and their VT_{2speed} (see Figure 4.2). To further understand the effect of using mean versus individual high-intensity thresholds, we closely observed data for two players. When using fixed thresholds (industry-used ($5 \text{ m}\cdot\text{s}^{-1}$) and mean VT_{2speed}), both players completed equivalent distances above each threshold. However, when GPS data were analysed based on individual VT_{2speed} thresholds, there was a 10% difference in the amount of running now completed at high intensity. The benefit, then, of expressing game movement patterns with an individualised threshold for high-intensity running allows for accurate quantification of running demands specific to the individual and prescription of effective training and recovery practices.

While individualised thresholds are beneficial for the monitoring of individual players, using a mean speed threshold for high-intensity running can provide coaches with a gross

understanding of the overall game intensity, as well as differentiate the aerobic fitness of players within a team. This can be seen through the moderate to large within-, and between-player correlations from this study. That aerobically fit players cover greater distances at high intensity has also been reported in other sports (100). In men's rugby sevens it has been shown that international level players complete 16% and 27% greater distances above 5-6 m.s⁻¹ and >6 m.s⁻¹ compared to national level players (90). However, it is important to use an appropriate speed threshold for high-intensity running as the distance spent above this threshold can change the outcome considerably among players when comparing a physiologically-defined and an arbitrary speed threshold (4). This may be particularly important for female rugby players as there is limited knowledge currently available.

The industry-used threshold of 5 m.s⁻¹, commonly used in men's team sport GPS analysis, correlates only with high-speed running capacity in women's rugby sevens players. Using this threshold, only those players who have a high sprinting ability are observed to work above this threshold during women's rugby sevens matches. The fact that the distance covered above 5 m.s⁻¹ had unclear correlations with % Sprint Distance, VT_{2speed}, and vVO₂ max further confirms the idea that players who sprint faster and cover more distance above 5 m.s⁻¹ do not necessarily have a higher work rate or the ability to sustain that performance over a game. The use of this high-speed threshold may still hold some worth in regards to training that focusses on development of high-speed sprinting ability, however, more research is required in this area to confirm or deny its applicability for this purpose.

This study confirms outcomes of previous research (120) and shows the importance of reporting running distances above a players' individual VT_{2speed} threshold. When individualisation is not available, however, a mean threshold of 3.5 m.s⁻¹ seems more appropriate than 5 m.s⁻¹ for reporting high-intensity running during women's rugby sevens games. Due to the limited number of rugby sevens players within each team, we encourage other international-level women's rugby sevens teams to consider the benefits of VO₂ max testing to individualise GPS thresholds for high-intensity running in both a competition and training setting. This study observed large confidence limits for a number of correlations and a larger subject pool may reduce some of this uncertainty and tighten the underlying precision of estimation. The method used for individualising high-intensity speed thresholds in this study, based on the work of Abt & Lovell (4), requires the implementation of a laboratory-based VO₂ max test, which can be time consuming and expensive. It can

also be difficult to complete in a team-sport setting due to limited available resources. In the situation where such testing is unable to be completed, we encourage the use of $3.5 \text{ m}\cdot\text{s}^{-1}$ as a more appropriate threshold, compared to the industry-used threshold of $5 \text{ m}\cdot\text{s}^{-1}$, in quantifying high-intensity running in female team sports when undertaking analysis of GPS data. Future research should also examine how playing level and phase of competitive season affects players’ $VT_{2\text{speed}}$.

Conclusion

In summary, we recommend an individualised approach to using GPS data for the assessment of high-intensity running in women’s rugby sevens. Use of an individualised VT_2 threshold provides an accurate assessment of game demands for each individual and can enhance the prescription of training and recovery requirements. The use of a fixed threshold value at $3.5 \text{ m}\cdot\text{s}^{-1}$ provides a summary of high-intensity game running demands which can be readily compared with other players, competitive matches, and sports. However, care must be taken when interpreting the level of high-intensity running undertaken by individual players. The widely used threshold of $5 \text{ m}\cdot\text{s}^{-1}$ inherited from men’s rugby union and sevens likely underestimates (by up to 30%) the volume of high-intensity running performed by female players and is not recommended for use in women’s rugby sevens. Instead, this threshold should be used only in relation to very high-speed running ability and potentially for the prescription of sprint training.

CHAPTER FIVE

Proof of concept of automated collision detection technology in rugby sevens

Clarke AC., Anson JM., Pyne DB., Proof of concept of automated collision detection technology in rugby sevens, *Journal of Strength and Conditioning Research*. Epub ahead of print, July 26, 2016.

Abstract

Developments in microsensor technology allow for automated detection of collisions in various codes of football, removing the need for time-consuming post processing of video footage. However, little research is available on the ability of microsensor technology to be used across various sports or sexes. Game video footage was matched with microsensor-detected collisions (GPSports) in one men's (n=12 players) and one women's (n=12) rugby sevens match. True positive, false positive and false negative events between video and microsensor-detected collisions were used to calculate recall (ability to detect a collision) and precision (accurately identify a collision). The precision was similar between the men's and women's rugby sevens game (~0.72; scale 0.00-1.00), however, the recall in the women's game (0.45) was less than for the men (0.69). This resulted in 45% of collisions for men, and 62% of collisions for women, being incorrectly labelled. Currently, the automated collision detection system in GPSports microtechnology units has only modest utility in rugby sevens and it appears that a rugby sevens-specific algorithm is needed. Differences in measures between the men's and women's game may be a result of physical size, strength, physicality and/or technical and tactical factors.

Introduction

Microsensor technology is used by many professional teams in a wide range of sports to monitor and manage the physical loads of players. This technology includes global position system (GPS) technology which can provide accurate estimates of running demands (102) to help direct training prescription, manage return-to-play, and reduce the risk of overtraining injuries. However, a key component that contributes to player load and risk of injury in various codes of football are physical collisions. Previously, quantifying collision events was only possible using the time-consuming and labour-intensive process of notational analysis. Recent developments in microsensor technology, however, include algorithms for quantifying impacts (g-force experienced during player movements) and collisions (physical contact between two or more players) (72). This functionality has the potential to more comprehensively capture game demands, accurately reflect player loads in games and training, and provide faster data feedback to coaching staff of contact sports such as rugby union, rugby league, American Football and Australian Football. However, few studies have explored the ability of microsensor technology to capture collisions and evaluate its usefulness in contact-based sports.

A number of different microtechnology units are available on the market that include the use of various microsensors. While GPSports units include tri-axial accelerometers, Catapult Innovations microtechnology units include a gyroscope and magnetometer in addition to a tri-axial accelerometer (206). Catapult units are reported to have good validity for measuring collision events in rugby union, compared to video-based analysis, using both raw and smoothed data (CV 9 – 15%) (206). Using GPSports microtechnology units, impacts (categorized as low to high g-forces), have a poor relationship with tackles and hit-ups in rugby league (128). However, movements such as a quick change of direction or a dive for a try elicit impacts rated small to moderate (<6.5 g-force) in magnitude (72). As such, the measurement of impacts does not differentiate high-impact running movements from physical collisions. A number of studies from varying collision-based sports (Australian Football (AFL), rugby union, rugby league) have attempted to quantify collision events using a combination of microsensor technology and video-based notational analysis (37, 69, 75, 128). Although reporting impacts in g-force may have limitations in accurately quantifying collisions, Kelly et al. (108) have developed an algorithm (employing static window features and a mathematical learning grid) to detect collision

events using the tri-axial accelerometer in GPSports microtechnology units. A similar algorithm, using accelerometer and impact data, is now commercially available within the company's software (Team AMS R1 2015.3). Using 15-player rugby union, combining microtechnology data and game footage, GPSports found a 90% success rate for automated collision detection (81). While the use of this automatic collision detection technology has reportedly been used in rugby league (37), no indication of how it related to video notational analysis was provided. Instead, collisions were identified during video footage and matched with the corresponding impact rating. Beyond this, automatic collision detection has not been used in an applied research setting and the ability of this software to accurately capture collision events requires independent evaluation. Given the GPSports brand is widely used by professional sporting organisations in rugby union and other collision-based sports, understanding the real-world applicability of collision data is warranted.

With the introduction of men's and women's rugby sevens to the Olympic Games in 2016 a substantial amount of research has gone into understanding the game demands of this sport, with many countries investing considerable amounts of time and money to reach professional status. Women's rugby sevens is one of the few female contact-based team sports that have an international competitive series (Women's Sevens World Series) each year. Previous research using GPS data to describe women's rugby sevens (25) identified the importance of female-specific speed thresholds for analysis of running movement patterns. With current research on collisions in contact sports derived from male game data (37, 72, 108), the microtechnology units may not accurately capture collisions in the women's game given differences in physical size and strength, tackle technique, or patterns of play. As such, female-specific collision algorithms may be required.

In addition, given that the software was developed originally to detect collisions within (15-player) rugby union, there may be some limitations applying this algorithm to other collision sports or formats. Collision events in rugby union are quite distinct in that several attacking and defending players are typically involved in competing for possession. Our assertion is that while rugby sevens games follow almost identical rules to rugby union, the difference in the number of players on the field (seven compared to fifteen) results in fewer players being involved in each tackle in rugby sevens. This difference may necessitate modifications to an automated algorithm that reflects true collisions in rugby sevens. The

aim of this proof-of-concept study was to assess the ability of automated collision-detection software in GPSports microtechnology units, in comparison with manually-coded video notational analysis, in an elite game of both men's and women's rugby sevens.

Methods

Experimental approach to the problem

Video-derived notational analysis was conducted on one men's and one women's international Sevens World Series game and matched with collision data obtained from microtechnology units (SPI HPU, tri-axial 100 Hz accelerometer, GPSports, Canberra, Australia).

Subjects

Twelve male (age 24.1 ± 3.2 y, height 1.84 ± 0.08 m, mass 92.0 ± 6.9 kg) and 12 female (age 22.8 ± 3.6 y, height 1.69 ± 0.02 m, mass 68.6 ± 4.4 kg) players were included in this study. Ethics approval was provided by the Australian Institute of Sport Ethics Committee and the University of Canberra Human Research Ethics Committee. Participants provided their written informed consent prior to involvement in this study.

Procedures

A microtechnology unit was worn by each player within a specialized pocket sewn into the playing jersey located between the scapulae (37, 69, 75). The threshold for detecting a collision using microtechnology was set at 3.5 g-force (following personal communication with the Athlete Performance Specialist at GPSports). The algorithm detects a collision when there is sufficient change to the position of the body in space (detected through the x, y, z components of the accelerometer) in combination with an impact above a set threshold (here 3.5 g). A single coder analysed video footage for collision events and repeated analysis on a subsample one month later to assess intra-individual test-retest reliability. The typical error of measurement was 6%. A manually-labelled collision was defined as one player collided with another in either an attacking or defensive role, during possession of the ball or immediately following ball release, as previously used by Garraway et al. (74) and Kelly et al. (108). These events can occur when a player is either giving or receiving a tackle, or when a tackle is attempted but is unsuccessful. The

measurement error in video-based notational analysis of the frequency, mean duration and total time of individual movement events has previously been reported as ~5-10% (51).

Three terms were used to describe the outcome of classifying events (Figure 5.1): true positive – microtechnology-detected collision was recorded alongside a manually-labelled collision; false positive – microtechnology-detected collision was recorded but not associated with a manually-labelled collision; false negative – a collision was manually-labelled but not recorded by microtechnology-detection. Manually-labelled collisions were classified as either attempted (tackler went to ground but was not successful in stopping the ball carrier) or completed (tackler successfully stopped the ball carrier advancing). Completed collisions were then coded for area of contact on the ball carrier (player can be either the ball carrier or tackler): legs (below the hips), torso (hips to chest) or high (shoulders and above).

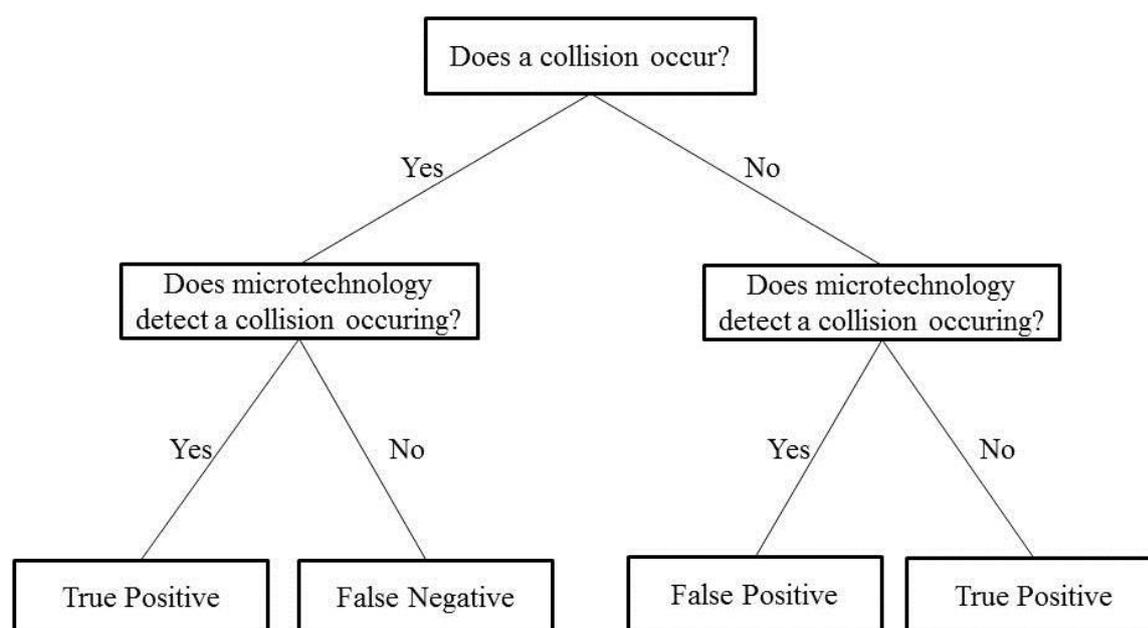


Figure 5.1. Graphical representation of how a collision event is classified when comparing video footage and microtechnology.

Statistical Analyses

Recall (ability to detect collisions with a low number of false negatives) and precision (ability to correctly detect collisions with a low number of false positives) were calculated as outlined in Kelly et al. (108). Recall (sensitivity) was calculated as the number of true positives divided by the sum of the number of true positives and false negatives. Precision was calculated as the number of true positives divided by the sum of the number of true positives and false positives. The best outcome that can be achieved is 1.0 for either precision or recall (i.e. no false positives or negatives), and, as such, a value of 0.5, for instance, indicates that 50% of collisions (in this case) are either not captured (poor recall), or incorrectly labelled (poor precision).

Results

The number of true positives, false positives and false negatives observed in the men's and women's games are reported in Table 5.1. During the men's game the algorithm incorrectly labelled collision events 45% of the time. Incorrect attribution during the women's game was higher at 62%. More specifically, the men's game had a recall of 0.69 and a precision of 0.73. The women's game had a recall of 0.45 and a precision of 0.71. On the occasions where a false positive event was reported, the event was one of three situations: the second attacking player in a breakdown competing for possession against an opponent, diving for a try, or, a fall following jumping in a lineout or from a kick-off.

Table 5.1. Observed GPS-detected collisions compared to manually-labelled collisions in an international World Series game of both men's (n = 12 players) and women's (n = 12 players) rugby sevens.

	Manually-labelled collisions (n)	True Positive (n)	False Positive (n)	False Negative (n)
Men	51	35	13	16
Women	44	20	8	24

Figure 5.2 shows the breakdown of attempted and completed collisions and the area of body impact for true positive and false negative events in completed collisions. For females, only 38% of completed collisions in the torso region were identified correctly via microtechnology, whereas 58% of collisions around the legs were detected. For the men,

there was a similar success rate of microtechnology to identify both leg and torso collisions (~73%).

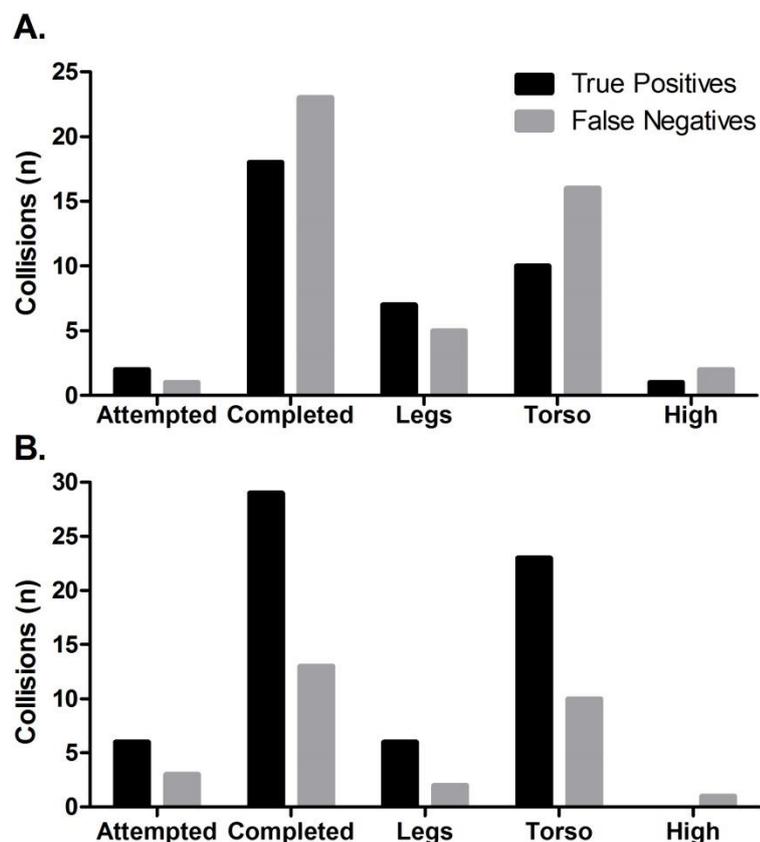


Figure 5.2. Attempted and completed collision events reported as either true positive (correctly detected via GPS) or false negative (incorrectly missed by GPS) events in a women's (A) and men's (B) rugby sevens game. Completed collision (attacking and defending) were further categorised into area of contact on the ballplayer.

Discussion

The precision and recall of quantifying collisions in men's and women's rugby sevens games (0.45 – 0.73) were substantially lower than previous reports in men's (15 player) rugby union using similar GPSports microtechnology units (SPI Pro), both of which include 100 Hz accelerometers (recall – 0.93, precision – 0.96) (108). While the precision of the system was similar between the men's and women's game, the ability to recall that a collision occurred was poorer for female players. Compared to the internal investigations

completed by GPSports in rugby union (81) showing a 90% success rate, it appears there may be substantial differences in collision events between rugby union and rugby sevens, as well as potential sex differences between the men's and women's game. While some rugby sevens-specific contact events appear to not be automatically detected using first generation algorithms, it may be possible to develop a rugby sevens-specific algorithm in the future. Furthermore, the difference between sexes also warrants further sex-based assessment of any rugby sevens-derived algorithm.

The ability of the system to recall collision events correctly in rugby sevens, with limited false negatives, was not as good as that reported in rugby union (81, 108). While the different algorithms used between studies may contribute in part, a number of collision events in rugby sevens went unrecognised, possibly due to tackles being one-on-one events or because the ball is quickly removed from a breakdown, therefore minimizing ball contests following a tackle. The poorer recall in the women's game may result from differences in physicality between men's and women's rugby sevens games. Research comparing elite men's and women's rugby sevens shows that men experience twice as many severe impacts (>10 g) than women (unpublished findings). An interesting result was a substantial difference in recall between collisions in the torso and legs region for female players, but not for men. Potentially, technical aspects of the collision or landing phases may result in this difference for female players. While lowering the g-force threshold used to classify a collision may reduce the number of false negatives, it would likely subsequently increase the number of false positives that are observed. Further research is required to understand the optimal threshold to use in the quantification of automatic collision detection. Potentially, given the influence of body mass in the calculation of g-force, larger players may actually require the use of a lower threshold. However, given the small positional differences in anthropometric profiles in men's (131) and women's rugby sevens (5) players, positional differences to collision threshold classifications may not be required. For female players, the pattern of accelerometer data during collision events may also differ, influencing the ability of the system to detect when a collision occurs. Further research is required to observe the different patterns of accelerometer data occurring during collision events in rugby sevens, with possible development of both men's and women's algorithms.

While the recall of the automatic-detection system differs between men and women, the precision of the system (detection of a positive collision event) was similar for both sexes. The occasions where a false positive occurred were also similar between the men's and women's game. However, given the poor recall of when a collision event occurs, the ability of the system that correctly identified only ~70% of the collisions detected requires further refinement in subsequent versions of the microtechnology accelerometer algorithm. A limitation of this study is the small number of subjects and game data observed. As development of the system becomes available, assessment of microsensor technology for collision detection using a greater number of games or players would be beneficial. Another area for development is the ability to detect stationary and static collision events, such as a scrum or when contesting in the ruck, given that the present algorithm requires changes within the three planes of movement (x, y, z) of the tri-axial accelerometer. While current microtechnology units are positioned between the scapulae, secondary force sensors could be applied to other areas of the body, such as the shoulders or feet, to help detect static applications of force.

Practical Applications

Given that the majority of acute match injuries are a result of physical collisions in men's (78%) (62) and women's (67%) (66) rugby sevens matches, understanding the physical contact loads on players is important for appropriate game preparation, training monitoring and management of players. However, automated detection of collisions using microtechnology developed for 15-player rugby union needs refinement for use in rugby sevens, especially for female players. Further work is required to understand the accelerometer patterns that occur with collisions in men's and women's rugby sevens. Studies that examine the validity and reliability of this algorithm in both controlled and applied settings, across both sexes, and in other collision-based sports are required before this technology can be confidently and widely used in applied and research settings.

CHAPTER SIX

Neuromuscular fatigue and muscle damage following a women’s rugby sevens tournament

Clarke, AC., Anson JM., Pyne DB., Neuromuscular fatigue and muscle damage following a women’s rugby sevens tournament, *International Journal of Sports Physiology and Performance*. 10: 808-814, 2015.

Abstract

Purpose: This study examined relationships between on-field game movement patterns and changes in markers of neuromuscular fatigue and muscle damage during a two-day women’s rugby sevens tournament. **Methods:** National (n = 12, 22.3 ± 2.5 y, 1.67 ± 0.04 m, 65.8 ± 4.6 kg; mean ± SD) and State (n = 10, 24.4 ± 4.3 y, 1.67 ± 0.03 m, 66.1 ± 7.9 kg) female representative players completed baseline testing for lower-body neuromuscular function (CMJ test), muscle damage (capillary creatine kinase (CK)), perceived soreness and perceived recovery. Testing was repeated after games on days one and two of the tournament. GPS (5 Hz) data were collected throughout the tournament (4-6 games per player). **Results:** National players were involved in greater on-field movements for total time, distance, high speed running (>5 m.s⁻¹), and impacts >10g (effect size (ES) = 0.55-0.97), and displayed a smaller decrement in performance from day one to day two. Despite this, State players’ had a much greater 4-fold increase ($\Delta\text{CK} = 737 \text{ U.L}^{-1}$) in CK compared to the 2-fold increase ($\Delta\text{CK} = 502 \text{ U.L}^{-1}$) in National players (ES = 0.73). Both groups had similar perceived soreness and recovery while CMJ performance was unchanged. High-speed running and impacts >10g were largely correlated (r = 0.66-0.91) with ΔCK for both groups. **Conclusion:** A two-day women’s rugby sevens tournament elicits substantial muscle damage, however, there was little change in lower-body neuromuscular function. Modest increases in CK can largely be attributed to high-speed running and impacts >10g that players typically endure.

Introduction

The inclusion of men’s and women’s rugby sevens to the Olympic Games for 2016 has seen an increase in the professionalization of sporting programs for these athletes. A detailed knowledge and understanding of the game demands and athletic requirements of players is crucial for success. Recent research in men’s rugby sevens has focussed on the running demands of competition (90). However, given the high degree of physical contact in rugby sevens, the issues of injury, muscle damage, soreness, and fatigue impairing performance are primary considerations for coaches and players. While some preliminary studies have investigated the presence and effect of neuromuscular fatigue and muscle damage induced by rugby sevens tournaments in males (179, 203), these questions have yet to be addressed in female rugby sevens players.

Rugby sevens is unique compared to other football codes in that while games are 14-20 min in duration, a tournament consists of up to three games played on a single day, over two to three consecutive days. In the Sevens World Series there is often less than one week separating consecutive international tournaments. The preparation of players to withstand high physical demands and recover adequately between games and tournaments is crucial. While the total distance that male players run during a game of rugby sevens (~1200-1600 m) is typically 3-4 times lower than in men’s rugby union (~4500-7000 m) (13, 33, 82, 173), rugby sevens players cover a greater relative distance and percent distance at high intensity, have a higher work to rest ratio, and are involved in a greater percentage of total tackles >10 g-forces (g) per game time (13, 33, 173). As a result of the nature of competitive rugby sevens tournaments, male players exhibit ~30% decline in neuromuscular function and a 500% increase in creatine kinase (CK), a marker of muscle damage (203).

The decline in players' neuromuscular function and appearance of muscle damage following rugby sevens tournaments appears similar in magnitude to that reported in other football codes. Competitive rugby union and rugby league matches result in 7-40% reduced neuromuscular function (measured via a countermovement jump (CMJ) test) and a 250-300% increase in CK for the 36-48 hours following a game (126, 128, 169, 204). Substantial correlations were also observed between changes in neuromuscular function and muscle damage and the number of physical impacts and tackles (126, 128, 169). However, while physical collisions yield an increase in CK concentration, the total number

of contacts only accounted for 55% of the variance (188), indicating that other non-contact activities also contribute to the rise in CK concentration following games and training (101). Post-game CK concentrations in soccer and Australian Football correlate positively with distances covered at high intensity, accelerating, decelerating and sprinting (184, 208). However, these CK values are lower than observed in rugby union and rugby league. Most likely then, muscle damage following a rugby sevens game or tournament reflects a cumulative effect of high intensity running demands as well as high physical impacts.

Players’ sex and physical fitness also appear to influence the degree of muscle damage and neuromuscular fatigue obtained following strenuous exercise. The degree of neuromuscular fatigue can be greater in men following strenuous exercise (183), while females generally have lower circulating levels of CK (135), probably related to the protective effect of oestrogen on muscle cell membranes (28). Physical fitness and exercise familiarity also influence players’ physiological responses to exercise (196), which subsequently alters the on-field movement patterns of players, and typically differs between playing levels in rugby (90, 100, 171). Currently, no research is available in female rugby sevens players on their physiological responses to competition or training at any playing level. Whether female and male players respond similarly to rugby sevens competition may depend on differences in player physiology, game movement patterns, and/or technical and tactical ability. This information is important for coaching staff to develop and implement sex-specific training and recovery programs.

The aim of this study was to compare on-field game movement patterns and subsequent changes in markers of neuromuscular fatigue and muscle damage in State and National representative players following a two-day women’s rugby sevens tournament. We also sought to characterize the relationship between indicators of muscle damage and lower body neuromuscular fatigue and on-field game movements.

Methods

Subjects

Australian National (n = 12, age 22.3 ± 2.5 y, height 1.67 ± 0.04 m, mass 65.8 ± 4.6 kg, mean \pm SD) and State representative women’s rugby sevens players (n = 10, 24.4 ± 4.3 y, 1.67 ± 0.03 m, 66.1 ± 7.9 kg) participated in this study, approved by the Australian Institute

of Sport Ethics Committee (approval number: 20140202) and the University of Canberra Human Research Ethics Committee (approval number: 14-02). The purpose, methodology, benefits and risks of this study were explained to all participants before obtaining their written informed consent.

National representative players included those currently competing for Australia in the Women’s Sevens World Series. For the Australian National Championships, these players returned to their home State teams to compete and so were playing in five different teams. All State representative players were within the same team, and did not gain selection for international representation that season.

Design

Observational research involving laboratory and game data was conducted during the 2014 Australian National Women’s Rugby Sevens Championships (a two-day tournament). All players arrived at the physiology laboratory (Australian Institute of Sport, Canberra, Australia) the day prior to tournament commencement to complete baseline testing. Capillary CK concentration, CMJ testing, and perceptual questionnaires were completed at baseline, and after completion of games on Day 1 and Day 2 of the tournament. All testing took place within a two-hour period each afternoon to reduce the effect of diurnal variation on measures. All data was collected in a controlled laboratory environment and testing was completed prior to the implementation of personal/team recovery strategies (e.g. cold water immersion, compression garments). While diet was not strictly controlled, all players had access to the same food choices for breakfast, lunch and dinner throughout the two-day tournament.

Methodology

Lower body neuromuscular function was measured using a CMJ test protocol. All players completed a set warm up prior to testing each afternoon which comprised the following: 3 min riding on a stationary bike at a moderate pace (~100 W), including two 5 s sprinting efforts within the final min; 30 s break; six body weight squats with hands on hips; 30 s break; four CMJ with arm swing, increasing efforts up to 100% by the final jump. Players then rested for 60 s before starting the test protocol. Players’ mass was measured with shoes on and recorded on the Gymaware handheld device (Kinetic Performance, Australia) prior to jumping. Testing was completed using a wooden broomstick placed behind their head

and rested on their shoulders, rather than a weighted bar to increase the compliance of the female players following strenuous exercise. Players completed two sets of six jumps at a self-selected dip depth. No more than 30 s rest was allowed between each jump repeat, however, players were instructed to reset and stabilize themselves before taking a subsequent jump. A one min break was provided between the two sets of jumps. Only the best set was reported as the mean and standard deviation (SD) of the six jumps, based on previous research (182) showing greater reliability in the measure when averaged over six reps. Reported measures include relative peak and mean power ($\text{W}\cdot\text{kg}^{-1}$), peak velocity ($\text{m}\cdot\text{s}^{-1}$) and dip height (m). Week-to-week coefficient of variation (CV) for these variables are 2.9-4.7% (182).

Capillary CK was used as an indirect marker of muscle damage. Whole blood (30 μL) was drawn from a finger prick and analysed using a Reflotron (Roche Diagnostics, Germany) as per the manufacturer instructions. The instrument was calibrated each day before testing and the day-to-day CV for CK was determined to be 8.3%.

Questionnaires were used to ascertain self-reported perceived soreness and recovery. The perceived soreness scale comprised an 11 point Likert scale (29), where 0 was not sore and 10 was extremely sore. The perceived recovery scale (116) had players report from 0 (very poorly recovered, extremely tired) to 10 (very well recovered, highly energetic). Plain language descriptors accompanied the numbers to assist players in identifying the most appropriate response.

Game movement data was collected on all participants using GPS units (5 Hz (interpolated to 15 Hz) SPI HPU, GPSports Systems, Canberra, Australia), which are considered valid and reliable for use in team-sports (38). Each unit was positioned between the scapulae using a specialized bib worn beneath the playing jersey. All games consisted of 2 x 7 min halves with 2 min half time, except for the Cup Final which was 2 x 10 min halves. Day One consisted of pool games, with finals on Day Two. Games were played between 9am and 4pm on both days (22-26°C, ~70% rel humidity). For analysis, the half time interval was excluded so that only on-field playing time was included. Of the National players, two players were injured at the end of Day One and did not compete in any games on Day Two. The remaining players competed in 5-6 games over the two days depending on finals progression of their team. Of the State players, not all players were involved in every game

due to coach selection; hence, players were involved in 4-6 games over the course of the tournament. Overall, a total of 64 game files for National players and 51 game files for State players were obtained. GPS data variables includes: duration (min), distance (m), relative distance ($\text{m}\cdot\text{min}^{-1}$), distance (m) covered at speeds; $<2 \text{ m}\cdot\text{s}^{-1}$, $2\text{-}3.5 \text{ m}\cdot\text{s}^{-1}$, $3.5\text{-}5 \text{ m}\cdot\text{s}^{-1}$, and $>5 \text{ m}\cdot\text{s}^{-1}$, as well as total number of impacts (n), impacts between 8-10 g-forces (g), and impacts $>10\text{g}$ (n). Total impacts include everything from severe physical collisions to light physical impacts and hard acceleration/deceleration or change of direction, whereas impacts 8-10g and $>10\text{g}$ are specific to very heavy and severe impacts only (69).

Statistical Analysis

Descriptive data is presented as the mean \pm SD. Raw data were log-transformed prior to analysis using inferential statistics. Data were analysed for all players across-days (within-tournament changes) and playing-level (State and National). Standardized mean change (Cohen’s effect size, ES) were used to characterize the magnitude of change against the following criteria: ES <0.2 trivial; 0.2-0.6 small; 0.6-1.2 moderate; 1.2-2.0 large; >2.0 very large (97). Precision of estimation was indicated with 90% confidence limits (CL). When the ES crossed the threshold of ± 0.2 the change (or difference) was deemed unclear. Preliminary analyses using a selective number of on-field running variables (including total distance, distance $>5 \text{ m}\cdot\text{s}^{-1}$, total impacts, and impacts $>10\text{g}$) were used as a covariant, however, no clear effects were observed and the results are not presented. Pearson’s Product-Moment correlation was used to assess the relationship between these select on-field movement metrics and change in CK (ΔCK) for each playing level. Correlations (r -value) were interpreted against the following criteria: $r < 0.1$ trivial; 0.1-0.3 small; 0.3-0.5 moderate; 0.5-0.7 large; 0.7-0.9 very large; and >0.9 almost certain (97). When the confidence interval spanned the threshold of ± 0.1 the association was deemed unclear.

Results

On-field game movement patterns

Table 6.1 shows the mean game movement patterns of State and National players over the two-day tournament. Players spent on average 38% of the total distance at low speeds ($<2 \text{ m}\cdot\text{s}^{-1}$), 30% between $2\text{-}3.5 \text{ m}\cdot\text{s}^{-1}$, 19% between $3.5\text{-}5 \text{ m}\cdot\text{s}^{-1}$, and 13% $>5 \text{ m}\cdot\text{s}^{-1}$. When game data was combined over the two days, National players were involved in moderately more game time (National 74 ± 22 min, State 50 ± 20 min, mean \pm SD; ES = 0.97, ± 0.69 ,

standardised mean, $\pm 90\%$ CL) and covered a greater total distance (National 7100 ± 2100 m, State 4800 ± 2200 m; ES = 0.85, ± 0.66). However, relative speed was not clearly different between the groups (National 96 ± 4 m.min⁻¹, State 94 ± 8 m.min⁻¹). While there were small to moderate differences between groups for distances covered at each speed threshold, when expressed as a percentage of total distance this difference became unclear. Total impacts (National 7300 ± 2200 , State 5200 ± 2400 ; ES = 0.75, ± 0.64) and the number of impacts $>10g$ (National 29 ± 11 , State 22 ± 11 ; ES = 0.55, ± 0.60) were also $\sim 30\%$ higher across the tournament for National players.

Both State and National players experienced substantial reductions in game movements on Day Two of the tournament. Large to very large reductions in relative running distance were evident for both State (-20% , $\pm 14\%$, mean, $\pm 90\%$ CL; ES = -3.36 , ± 1.56) and National (-8% , $\pm 5\%$, ES = -1.27 , ± 0.48) players. State players also had a small decrease in total distance covered (-10% , $\pm 22\%$, ES = -0.32 , ± 0.39) and a large decrease in percent distance covered >5 m.s⁻¹ (-33% , $\pm 37\%$, ES = -1.79 , ± 1.16), while percent distance covered at speeds between $2-3.5$ m.s⁻¹ increased (13% , $\pm 9\%$, ES = 1.00 , ± 0.39). National players experienced a moderate decrease in percent distance covered >5 m.s⁻¹ (-18% , $\pm 27\%$, ES = -0.60 , ± 0.49) and a small increase in percent distance covered <2 m.s⁻¹ (2% , $\pm 6\%$, ES = 0.24 , ± 0.31). Changes in all other measures were unclear between Day One and Day Two.

Table 6.1. Differences in game movement patterns of State and National players over a two-day women's rugby sevens tournament (mean \pm SD).

	Day One				Day Two			
	State (n=10)	National (n=12)	ES, \pm 90% CL	Qualitative Difference	State (n=10)	National (n=10)	ES, \pm 90% CL	Qualitative Difference
Playing duration (min)	23 \pm 10	37 \pm 8	1.32, \pm 0.63	Large +	27 \pm 11	44 \pm 7	1.23, \pm 0.56	Large +
Distance covered (m)	2533 \pm 1103	3680 \pm 900	0.90, \pm 0.58	Moderate +	2267 \pm 1174	4087 \pm 591	1.21, \pm 0.55	Large +
Relative Distance (m.min ⁻¹)	105 \pm 7	100 \pm 7	-0.69, \pm 0.68	Moderate -	83 \pm 14	93 \pm 4	0.61, \pm 0.54	Moderate +
D <2 m·s ⁻¹ (m)	942 \pm 397	1399 \pm 359	0.95, \pm 0.59	Moderate +	821 \pm 374	1592 \pm 205	1.32, \pm 0.54	Large +
D 2-3.5 m·s ⁻¹ (m)	711 \pm 328	1104 \pm 345	0.95, \pm 0.61	Moderate +	704 \pm 375	1211 \pm 235	1.18, \pm 0.56	Moderate +
D 3.5-5 m·s ⁻¹ (m)	524 \pm 244	706 \pm 224	0.65, \pm 0.59	Moderate +	513 \pm 330	774 \pm 160	0.84, \pm 0.55	Moderate +
D >5 m·s ⁻¹ (m)	356 \pm 181	472 \pm 183	0.52, \pm 0.63	Small +	228 \pm 166	492 \pm 183	0.87, \pm 0.55	Moderate +
Total Impacts (n)	2642 \pm 1187	3855 \pm 974	0.87, \pm 0.58	Moderate +	2519 \pm 1353	4126 \pm 989	1.00, \pm 0.57	Moderate +
Impacts 8-10g (n)	26 \pm 18	32 \pm 14	0.39, \pm 0.59	Unclear	23 \pm 17	34 \pm 24	0.56, \pm 0.58	Small +
Impacts >10g (n)	12 \pm 7	15 \pm 6	0.41, \pm 0.57	Small +	10 \pm 5	17 \pm 9	1.05, \pm 0.66	Moderate +

ES = effect size, CL = confidence limits, D = distance, + higher in National players, - lower in National players.

Off-field performance measures

Perceptual Questionnaires: Perceived recovery declined substantially by a mean of 2 points (on a 11 point scale) in both State (ES = -1.91, \pm 1.90) and National (ES = -1.26, \pm 0.80) players, while perceived soreness had a large mean increase of 3 points, ranging from being ‘uncomfortable’ to ‘very sore’ at the end of Day Two for both groups (ES = 1.31 – 2.38, \pm ~0.95). There was no difference in perceived recovery or soreness between playing levels at any time point.

Neuromuscular function: At baseline, National players had greater peak power (mean difference 15%, \pm 14%, State 56 ± 10 W.kg⁻¹, National 64 ± 9 W.kg⁻¹), mean power (+18%, \pm 15%, State 33 ± 7 W.kg⁻¹, National 39 ± 4 W.kg⁻¹), and peak velocity (+6%, \pm 7%, State 3.0 ± 0.3 m.s⁻¹, National 3.2 ± 0.2 m.s⁻¹), with small to moderate differences at each time point. Over the tournament, however, there was no substantial change in CMJ performance for either group. Variation in jump performance within a test set (SD of reps) exhibited small to moderate increases in variables for both State and National players over the tournament, although little difference was observed between groups (data not shown).

Muscle damage: Both groups had large to very large 2-fold (National players) and 4-fold (State players) increases in CK concentration by the end of the tournament. While there was no substantial difference in capillary CK concentration at any time point between groups, relative to baseline, CK exhibited small to moderately (ES = 0.48–0.73) greater increases in State players (Δ CK Day One 325 ± 232 U.L⁻¹, Day Two 737 ± 548 U.L⁻¹) compared to National players (Δ CK Day One 273 ± 183 U.L⁻¹, Day Two 502 ± 317 U.L⁻¹) (Figure 6.1). In State players, Δ CK from baseline to Day Two positively correlated with distance covered >5 m.s⁻¹ ($r = 0.66$, 0.05–0.91; mean, 90% confidence interval) and the number of impacts $>10g$ ($r = 0.90$, 0.63–0.98). Whereas National players had large to almost certain ($r = 0.58$ –0.91) positive correlations between Δ CK and total distance, distance >5 m.s⁻¹, and impacts $>10g$ (Figure 6.2).

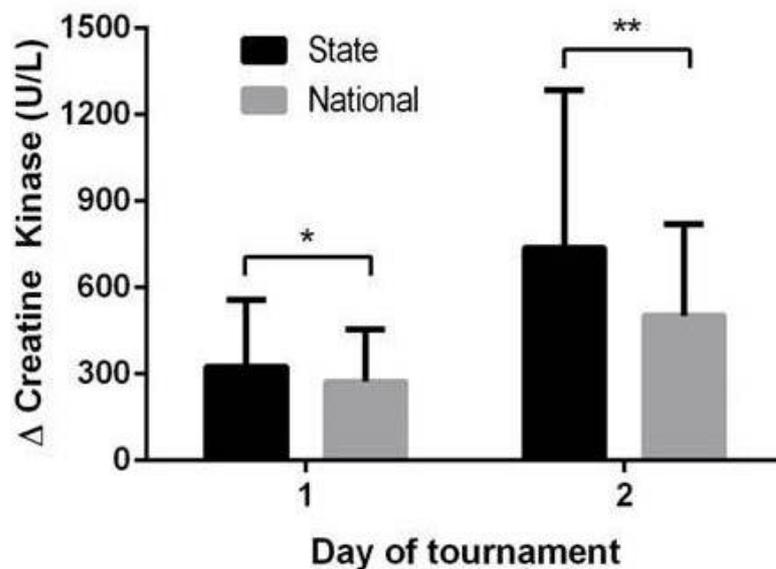


Figure 6.1. Change in capillary creatine kinase concentration compared to Baseline over a two-day women’s rugby sevens tournament in State (n=10) and National (n=12) players. Small (*) and moderate (**) differences between playing levels are indicated.

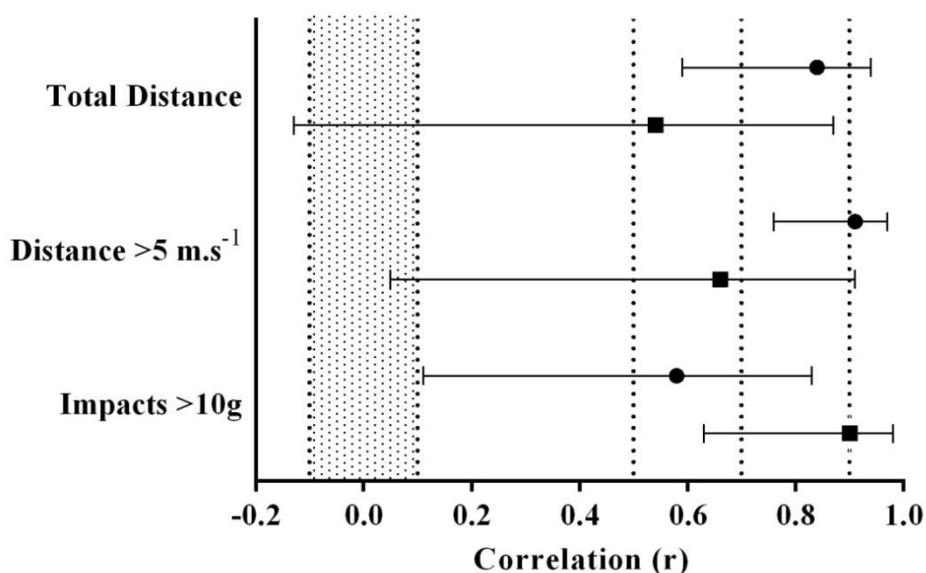


Figure 6.2. Correlation between on-field game metrics and the change from baseline to Day Two capillary kinase concentration following a two-day women’s rugby sevens tournament in State (■, n=10) and National (●, n=12) players. Data presented are r -value with 90% confidence intervals. Shaded area between ± 0.1 shows the area of uncertainty. Dotted lines separate large (0.5-0.7), very large (0.7-0.9) and almost certain (>0.9) correlations.

Discussion

This study showed that National players completed substantially higher on-field game movement demands than State players over a two-day women’s rugby sevens tournament. National players also experienced less physiological and perceptual disturbance and were able to better maintain their performance across the two-day tournament compared to State players. Interestingly, the change in CK over the two-day tournament positively correlated with all on-field game measures in National players, however, only distance covered $>5 \text{ m.s}^{-1}$ and the number of impacts $>10\text{g}$ correlated with the increase in CK in State players.

Differences between the game movement patterns of State and National players were primarily moderate in magnitude and increased from Day One to Day Two; likely a result of greater fatigue in State players. While National players appeared to maintain their level of movement, State players game movement patterns declined markedly over the course of the tournament. Reduced running may be evidence of fatigue in State players, possibly due

to poorer physical fitness (100). With greater aerobic fitness, larger workloads can be completed with less physiological disturbance (55, 196). The National players in this study were midway through the Women’s Sevens World Series when the National Championships were conducted. Presumably, the training and national and international competitions that these players had already completed meant they were more accustomed to the physical demands of rugby sevens tournaments. The State players, while competing in local regional tournaments during their preparation, were likely less adequately prepared. Training for the State players leading into the tournament was reported at approximately two to three times per week, with only a small portion at full intensity with heavy contact situations. Greater muscle damage and increased psychological disturbance compared to baseline likely impaired their on-field physical performance on Day Two of the competition.

While player fitness is likely one contributing factor to differences observed between State and National players in this study, the technical and tactical proficiency of players (71) may also influence game movement patterns and their physiological responses. While not measured explicitly, likely higher aerobic capacity and physical qualities (73) of National players may have contributed to their ability to complete greater on-field running and physical impacts during match play, while also displaying a lower decrement in running performance from Day One to Day Two of the tournament (Table 6.1). However, the match experience of National players, with highly developed technical and tactical skills (71) may also contribute to the coach’s choice to have them on the field for longer with more involvement in match play. While small to moderate differences were apparent in the number of impacts State and National players were involved in, the technical proficiency of National players to give or receive a dominant tackle may have facilitated them being able to complete more tackles, with a lower subsequent rise in muscle damage markers. The almost certain (positive) correlation between the number of impacts >10g and the rise in CK for State players indicates that heavy impacts are a major contributor to muscle damage for these players who may not be as aerobically fit, accustomed to such exercise and/or technically proficient. Despite differences in on-field running and the resultant increase in CK, limited differences were observed with players’ perceived soreness and recovery, consistent with the idea that perceived wellbeing and CK response are not directly related (196). A limitation of this study was that the physical, physiological and technical ability of players was not assessed and future research should look to compare these aspects

between playing levels in women’s rugby sevens. This information is warranted to gain a greater understanding of the physical requirements of players within each level of competition, and enhance the progression of players’ from state to national and international representation.

Quantifying match demands of women’s rugby sevens games is important not only for the appropriate prescription of training, but also to inform the amount and type of recovery needed following training or competition. The proportion of high-speed running (% distance $>5 \text{ m}\cdot\text{s}^{-1}$) in this study was similar or greater than previously reported in elite female rugby sevens players (175, 207). However, when attempting to quantify the physiological demands of competition and the subsequent recovery required, an absolute measure of high-speed running may be more informative. In this study, both State and National players had similar relative contributions of high-speed running to their total distance covered, despite National players covering $\sim 50\%$ greater absolute distance. Given that distance covered at high-speed contributes to muscle damage and neuromuscular fatigue (184, 208) the reporting of absolute measures is important for understanding the recovery time needed after tournaments and training.

The magnitude of muscle damage induced by a two-day women’s rugby sevens tournament is similar to men’s rugby sevens players (179, 203), and greater than women’s soccer players (8). CK concentrations in female rugby sevens players is similar to their male counterparts following two consecutive games ($\sim 500 \text{ U}\cdot\text{L}^{-1}$) (179) and a two-day international tournament ($\sim 900 \text{ U}\cdot\text{L}^{-1}$) (203). It is possible the amount of work performed by male rugby sevens players at an international level (game movement data not reported) was greater than reported during this study despite the similar end-of-tournament CK values (173, 203). How the female National players from this study would respond at international-level tournaments is uncertain.

The CK response in our female players to a national two-day rugby sevens tournament were greater than those reported in female soccer players (90 min game, CK $\sim 240\text{-}340 \text{ U}\cdot\text{L}^{-1}$) (8, 83). This difference in CK concentration between female rugby sevens and soccer players is similar in male counterparts (184, 203) and likely related to the combined effect of high intensity running with intense physical collisions in rugby (101, 126, 188, 208). While the elevation in CK could not be explained by any single GPS running metric in this

study, there were large to very large correlations between Δ CK and the degree of on-field running and impacts. The dissimilar relationship between CK concentration and impacts in State and National players emphasises the importance of exposing players to intense and physically demanding training sessions in order to adequately prepare players for rugby sevens competition.

Interestingly, despite absolute differences in CMJ performance between State and National players, there were no clear changes in performance and only small changes in the variability of jumps within a set over the course of the tournament. These results differ from those observed in male rugby sevens players who exhibited a 26% decline in jump height following a two-day tournament (203). Different protocols and equipment may account for some differences in these results, however, the use of recovery strategies following each day of competition in this study (including cold water immersion, compression garments, foam rolling, stretching) may also have limited the extent of neuromuscular fatigue of players (149), and should be documented in future research. Given the high physical contact nature of rugby sevens, it may be worthwhile to include measures of upper body neuromuscular function (101) in future research also.

Practical Applications

High-speed running ($>5 \text{ m}\cdot\text{s}^{-1}$) and impacts $>10\text{g}$ are major contributing factors to the amount of muscle damage players exhibit and their measurement aids the prescription of recovery. Given that players of higher rank can perform more on-field movements with less fatigue and damage, a greater emphasis on training (particularly high-speed running and intense physical impacts) is required to adequately prepare players for intensified rugby sevens tournaments. In lieu of that, players of lower playing rank may require a longer recovery period following tournaments to recover from the heightened disturbance compared to players of higher rank.

Conclusions

A two-day women’s rugby sevens tournament elicits modest muscle damage and a heightened sense of perceived soreness and delayed recovery, however, little change is seen in lower-body neuromuscular jumping performance. State players exhibited greater

physiological disturbance than National players, despite being involved in less on-field games running and impacts. The greater response in State players is potentially related to poorer physical fitness, being unaccustomed to the high physiological demands of rugby sevens match play, and exacerbated by less resilience to damaging tackles and collisions.

CHAPTER SEVEN

The effect of running demands and impacts on post-tournament markers of inflammation and haemolysis in women’s rugby sevens

Clarke, AC., Anson JM., Pyne DB., The effect of running demands and impacts on post-tournament markers of inflammation and haemolysis in women’s rugby sevens, *New Zealand Journal of Sports Medicine*. 42: 70-76, 2015.

Chapter 7

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Abstract	
<p>Aim Rugby sevens is a physically demanding sport often leaving players fatigued and sore. This study aimed to quantify the short-term changes in biochemical and haematological variables of inflammation and haemolysis induced by a two-day women's rugby sevens tournament in State and National representative players, and explore the relationship between on-field movement patterns and select biomarkers. Study Design cross-sectional study. Setting Australian Women's rugby Sevens national championships. Participants State (n = 10, 24.4 ± 4.3 y, 1.67 ± 0.03 m, 66.1 ± 7.9 kg) and national (n = 12, age 22.3 ± 2.5 y, height 1.67 ± 0.04 m, mass 65.8 ± 4.6 kg) female rugby sevens players. Outcome Measures running movement patterns and impacts were recorded using 15 Hz GPS units over a two-day tournament. Biochemical and haematological variables were measured before and after the tournament. Results While National players completed greater on-field movements (effect size (ES) = 0.55-0.97), post-tournament leukocyte count increased similarly (30-50%) in both State (ES = 1.95) and National players (ES = 1.52). Neutrophil count positively correlated (r = 0.57-0.89) with all on-field movements for both groups. Haptoglobin concentration were 94% higher at baseline in National players (ES = 1.33), but declined ~20-40% in both groups. Creatine kinase increased 4-fold in State players, and 2.5-fold in National players (ES = 2.86-4.10), while creatinine increased moderately (10-14%) in both groups. Conclusion Greater haemolysis and muscle damage in State level players might be a consequence of lower strength and fitness, and being less accustomed to the contact demands of competition. Effective preparation and careful post-tournament management of players should promote improved game performance and enhanced recovery</p>	

CHAPTER EIGHT

Females at risk: Iron monitoring of male and female rugby sevens players over an international season

Clarke AC., Anson JM., Dziedzic CE., McDonald WA., Pyne DB., Females at risk: iron monitoring of male and female rugby sevens players over an international season. *British Journal of Sports Medicine*. In review.

Abstract

Background/Aim: Given the likely influence that high training loads, contact-induced haemolysis and female-specific requirements have on the incidence of iron deficiency, characterising the direction and magnitude of fluctuations in iron status over an international season is important for managing player health and physical performance in rugby sevens.

Methods: Australian national male (n=27) and female (n=23) rugby sevens players undertook blood tests at pre-season, mid-season, and end-season. Haemoglobin (Hb), haematocrit (Hct), ferritin, transferrin and transferrin saturation were quantified. Female athletes also reported oral contraceptive use and a subset (n=7) provided 7-day food diaries to quantify iron intake.

Results: Male players typically had a three-fold higher ferritin concentration than females. Pre-season ferritin concentrations in male ($151 \pm 66 \mu\text{g/L}$; mean \pm SD) and female ($51 \pm 24 \mu\text{g.L}^{-1}$) players declined substantially (~20%) by mid-season, but recovered by end-season. Over the season 23% of female players were classified as iron deficient (ferritin $<30 \mu\text{g.L}^{-1}$) and prescribed supplementation. The greatest incidence of iron deficiency in female players occurred mid-season (30%). Oral contraception and dietary iron intake had an unclear influence on female players' ferritin concentration. All other haematological variables were within normal physiological ranges.

Conclusion: Given the relatively low ferritin concentrations evident in female rugby sevens players, and the potential for a further decline midway through a season when physical load may be at its highest, 6-monthly haematological reviews are suggested in combination with dietary management. Annual screening may be beneficial for male players, with further monitoring only when clinically indicated.

Introduction

Monitoring iron stores in athletes can be beneficial for managing general health and factors contributing to performance. While clinical anaemia is the end-point of low iron stores, inhibiting the body's ability to produce new red blood cells, absolute and functional iron deficiency can also negatively affect general health, as well as performance in athletes. The presence of clinical anaemia is relatively rare (~4-7%) in athletes (110), however, sub-clinical presentations are more common and could impair athletic performance. An athlete's physical capacity to train (44, 96), mental state (concentration, decision making, perceived effort) (20, 112), and ability to recover and adapt (19, 210) can be negatively affected by low iron stores.

Ferritin concentration is commonly used to identify low iron stores (deficiency) in individuals. However, the thresholds for classifying low iron (and associated terminology) are inconsistent in clinical and research settings. While a ferritin $<12 \mu\text{g.L}^{-1}$ is universally regarded as critically low (anaemic) (110), iron deficiency is more contentious, with $30 \mu\text{g.L}^{-1}$ (156) and $35 \mu\text{g.L}^{-1}$ (110, 130) both commonly used cut-offs below which iron supplementation may be prescribed for athletes. The term "functional iron deficiency", where performance (rather than health) may be negatively impacted, is between $30\text{-}99 \mu\text{g.L}^{-1}$, or $100\text{-}299 \mu\text{g.L}^{-1}$ when combined with a transferrin saturation $<20\%$ (156). Depending on whether iron monitoring is performed for clinical health, physiological adaptation, or altitude training (80), the threshold applied may differ.

In athletes, iron deficiency is the result of an accelerated turnover of blood (haemolysis), exercise-mediated hepcidin release (144), increased sweat volume and urine output (24), and possibly inadequate dietary iron intake. Iron deficiency has been identified as a limiting factor in endurance performance (85), hence the majority of descriptive and intervention studies involve endurance athletes. Although quantifying the effects of impaired iron status on intermittent team-sport performance is more difficult, a substantial number ($>30\%$) of team-sport players present with low iron stores (49, 156) that may compromise training and performance.

Across a competitive season haematological parameters fluctuate in response to training load and adaptation, although little information is available on rugby players. The largest

fluctuations occur in endurance-trained athletes, however, strength/power athletes and team-sport players' parameters also vary, albeit to a lesser degree (18). One study in rugby union players (17) showed small variations in haemoglobin (Hb), haematocrit (Hct), and ferritin during a competitive season, likely in response to periods of heavy training and/or competition. However, all measures remained within normal physiological range and were not deemed of clinical importance. It is unknown how the different tournament format of rugby sevens affects haematological parameters across a competitive season.

Female rugby sevens players may be at greater risk of iron deficiency than male players due to the combination of high physiological demands (training/competition) with female-specific issues of menstruation and possibly inadequate dietary iron intake. Iron deficiency is reported in ~50% of female athletes (110, 130, 141) and non-athletes (45, 165). Limited data are available on the iron status of female athletes over a competitive season and so the effects of training and competition are unclear. Due to menstrual blood flow, eumenorrheic females lose a mean total of 1.4 mg.day⁻¹ of iron (endurance-trained female athletes, 2.3 mg.day⁻¹), compared to 1.0 mg.day⁻¹ (non-athlete) or 1.7 mg.day⁻¹ (athlete) in males (201). On this basis, the recommended dietary iron intake for women (18 mg) is double that of men (8 mg) (22). Oral contraceptives have been promoted as a means to limit the detrimental effects of menstruation on iron stores by reducing the amount of blood lost during menses (99, 115).

It is important to understand the fluctuations in iron status of male and female rugby sevens players throughout a competitive season to inform appropriate haematological monitoring for general health and physical performance. While the number of clinical presentations of anaemia is likely small in this population (male and female), sub-clinical depletion of iron stores may influence a player's ability to train, recover, and perform. The aim of this study was to quantify the direction and magnitude of haematological changes in male and female rugby sevens players over a competitive season, with a particular interest in quantifying the incidence of iron deficiency in female players.

Methods

We conducted a longitudinal, observational case study involving national-level male (n=26, 23 ± 3 y, 1.85 ± 0.06 m, 90.1 ± 8.4 kg; mean ± SD) and female (n=23, 24 ± 5 y, 1.72 ± 0.05

m, 69.1 ± 6.3 kg) rugby sevens players. Blood tests were undertaken at pre-season (September, approximately three weeks into pre-season training), mid-season (February-March, half-way through the international season) and end-season (May-June, within two weeks of the final tournament), to quantify the full blood count and iron profile of players. All players were informed of the study design, methods, benefits and risks, prior to providing their written consent. This study was approved by the Australian Institute of Sport Ethics Committee and the University of Canberra Human Research Ethics Committee.

Players were in a rested state (≥ 24 hrs of no training) prior to blood collection. Venous blood (4 mL) was collected via venepuncture following players resting in a seated position for several minutes. Common/standard haematological parameters (Tables 8.1 and 8.2) were analysed using a Sysmex XT-2000i (Roche Diagnostics, Australia). Biochemical analysis of iron, ferritin, transferrin and transferrin saturation using serum was performed on a Cobas Integra 400 plus (Roche Diagnostics, Australia). All analytes underwent internal and external quality control checks prior to analysis. Ferritin concentration (main variable) CV = 13.5%.

No player had a medical condition which would cause abnormal haematological parameters. At the time of testing, no player was sick or injured (unable to train), nor were taking iron supplements prior to this study. At each blood collection, oral contraceptive use by female players was recorded. No players were supplemented with iron at the beginning of this study. During pre-season, and under the direction of a dietitian, a sub-sample of seven female players completed a seven-day food diary that was analysed for dietary iron (FoodWorks 8 Professional, Xyris Software, Brisbane, Australia). The number of international tournaments played during the season by each squad member (male and female) was recorded.

Data are presented as mean \pm SD. Raw data were log-transformed prior to analysis. Standardised mean difference or change (Cohen's effect size, ES) between groups and time points were used to characterise the magnitude, according to the following criteria: ES < 0.2 trivial; 0.2-0.6 small; 0.6-1.2 moderate; 1.2-2.0 large; and > 2.0 very large (97). Precision of estimation was indicated with 90% confidence limits (CL). The difference (or change) was deemed unclear where the CL crossed both standardised thresholds of +0.2 and -0.2.

Pearson's product-moment correlation was used to characterise the relationships between ferritin concentration and age and dietary iron intake, interpreted against the following criteria: $r < 0.1$ trivial; 0.1-0.3 small; 0.3-0.5 moderate; 0.5-0.7 large; 0.7-0.9 very large; > 0.9 almost certain (97). When the 90% confidence interval (CI) spanned the threshold of ± 0.1 the association was deemed unclear.

Results

A schematic diagram of selected reference ranges often used to classify low ferritin concentration is presented in Figure 8.1. All parameters were within a normal range for men (Table 8.1). A small between- (-18% , $\pm 20\%$; mean, $\pm 90\%$ CL) and within-subject (-18% , $\pm 12\%$) decline in ferritin occurred from pre- to mid-season (Figure 8.2). This corresponded with between-subject (24% , $\pm 28\%$) and within-subject (29% , $\pm 39\%$) improvements in transferrin saturation mid-season. Only two male players' ferritin concentrations increased from pre- to mid-season. Both players did not compete in any tournaments in the first half of the season, whereas the remaining players had competed in 3-5 tournaments by mid-season. Hb (-3% , $\pm 2\%$) and Hct (-5% , $\pm 2\%$) declined (within-subject) from mid- to end-season (ES = -0.48 to -1.04 , $\pm \sim 0.40$; standardised difference, $\pm 90\%$ CL), while ferritin restored to pre-season values. Men had approximately three-fold greater ferritin concentration than women (ES = 3.97 , ± 0.74). When normalised for body mass, this difference remained clear (ES = 3.05 , ± 0.78).

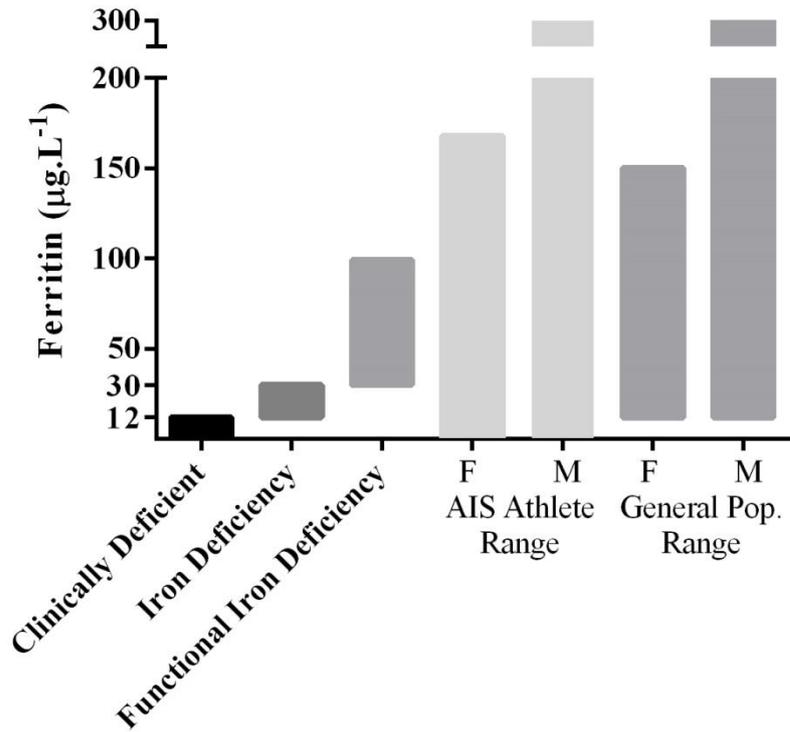


Figure 8.1. Reference ranges frequently used to assess ferritin concentration in the general and athletic population. AIS Athlete range: Australian Institute of Sport reference range derived from healthy athlete samples (mean \pm 95% confidence interval), F; female, M; male, pop; population. When F and M are not specified, reference range refers to both sexes.

Table 8.1. Mean blood profile of male rugby sevens players throughout an international season. Mean \pm SD.

	Pre-Season (n=15)	Mid-Season (n=19)	End-Season (n=17)
Iron ($\mu\text{mol.L}^{-1}$)	16.9 \pm 7.0	18.4 \pm 5.4	18.0 \pm 5.0
Ferritin ($\mu\text{g.L}^{-1}$)	151 \pm 66	121 \pm 45*	161 \pm 47**
Transferrin (g.L^{-1})	2.80 \pm 0.33	2.58 \pm 0.29**	2.56 \pm 0.33
Transferrin Sat (%)	22.8 \pm 8.9	27.0 \pm 7.0*	26.9 \pm 7.4
RBC ($10^{12}.\text{L}^{-1}$)	5.03 \pm 0.34	5.29 \pm 0.30**	5.10 \pm 0.32**
Hb (g.L^{-1})	14.8 \pm 0.9	15.4 \pm 0.7**	15.1 \pm 0.7*
Hct (%)	43.1 \pm 2.5	44.7 \pm 2.1**	42.5 \pm 1.7**
MCV (fL)	85.7 \pm 2.8	84.5 \pm 3.7	83.5 \pm 3.6
MCH (pg)	29.4 \pm 0.7	29.2 \pm 1.2	29.6 \pm 1.2
MCHC (g.L^{-1})	34.4 \pm 0.9	34.5 \pm 1.0	35.4 \pm 1.0**
RDW-CV(%)	12.5 \pm 0.7	12.6 \pm 0.6	12.5 \pm 0.6
PLT ($10^9.\text{L}^{-1}$)	229 \pm 30	228 \pm 51	243 \pm 46*
WBC ($10^9.\text{L}^{-1}$)	6.15 \pm 0.84	5.96 \pm 2.09	6.74 \pm 1.52*
Neutrophils ($10^9.\text{L}^{-1}$)	3.72 \pm 0.82	3.32 \pm 1.58*	3.91 \pm 1.07*
Lymphocytes ($10^9.\text{L}^{-1}$)	1.66 \pm 0.30	1.82 \pm 0.57	1.92 \pm 0.51
Monocytes ($10^9.\text{L}^{-1}$)	0.56 \pm 0.15	0.50 \pm 0.16*	0.53 \pm 0.12
Eosinophils ($10^9.\text{L}^{-1}$)	0.19 \pm 0.13	0.30 \pm 0.52	0.35 \pm 0.51
Basophils ($10^9.\text{L}^{-1}$)	0.015 \pm 0.008	0.016 \pm 0.010	0.024 \pm 0.009*

Sat, saturation; RBC, red blood cell; Hb, haemoglobin; Hct, haematocrit; MCV, mean cell volume; MCH, mean corpuscular haemoglobin; MCHC, mean corpuscular haemoglobin concentration; RDW-CV, red blood cell distribution width; PLT, platelets; WBC, white blood cell. Small (*) and moderate (**) between-subject differences from pre- to mid-season, and mid- to end-season are presented.

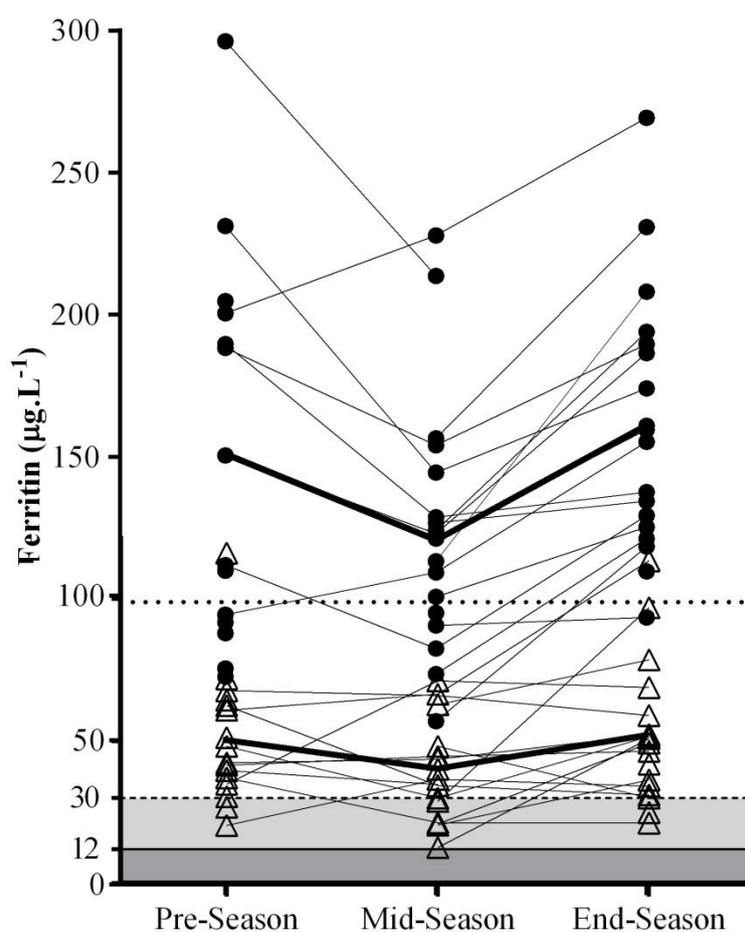


Figure 8.2. Ferritin values of male (circles) and female (triangles) rugby sevens players over a competitive season. Dark line represents mean changes for male and female players. Solid line at $12 \mu\text{g.L}^{-1}$ represents clinical deficiency cut-off, shaded area below the dashed line represents iron deficiency ($30 \mu\text{g.L}^{-1}$), below the dotted line (without shading) represents functional iron deficiency ($99 \mu\text{g.L}^{-1}$).

The blood profiles for female players are presented in Table 8.2. There was a small 22% ($\pm 23\%$) decline in ferritin concentration (between-subject) from pre- to mid-season (-0.54 , ± 0.61 standardised difference, $\pm 90\%$ CL), which improved (30%, $\pm 37\%$) from mid- to end-season (0.51 , ± 0.54 , Figure 8.2). Within-subject analysis showed no clear decline at mid-season (-0.05 , ± 0.44). When iron supplemented players were removed from end-season results, no clear change occurred from mid- to end-season (0.44 , ± 0.77). Of the two players who improved their ferritin from pre- to mid-season, one was given iron supplementation

and the other did not compete internationally. Within-subject analysis showed transferrin declined by 12% mid-season ($-0.64, \pm 0.36$) but recovered by end-season, while transferrin saturation continued to decline from pre- to end-season ($-0.87, \pm 0.70$). Hb and Hct were lowest during mid-season testing following small to moderate within-subject declines from pre-season (-0.55 to $-1.02, \pm \sim 0.41$; range of standardised changes, $\pm 90\%$ CL). The lowest ferritin concentration ($13 \mu\text{g.L}^{-1}$) occurred mid-season, with a Hb of 13.9 g.L^{-1} (no pre-season test).

Table 8.2. Mean blood profile of female rugby sevens players throughout an international season. Mean \pm SD.

	Pre-season (n=15)	Mid-Season (n=16)	End-Season (n=17)
Iron ($\mu\text{mol.L}^{-1}$)	19.7 ± 6.4	17.4 ± 6.8	15.5 ± 5.6
Ferritin ($\mu\text{g.L}^{-1}$)	51 ± 24	$40 \pm 18^*$	$52 \pm 25^*$
Transferrin (g.L^{-1})	3.10 ± 0.59	3.03 ± 0.61	$3.22 \pm 0.40^*$
Transferrin Sat (%)	24.1 ± 5.7	22.4 ± 9.1	$18.4 \pm 6.6^*$
RBC ($10^{12}.\text{L}^{-1}$)	4.62 ± 0.35	4.59 ± 0.27	4.65 ± 0.15
Hb (g.L^{-1})	13.6 ± 0.8	13.6 ± 0.9	13.8 ± 0.6
Hct (%)	40.3 ± 2.1	$39.2 \pm 2.5^*$	39.9 ± 1.6
MCV (fL)	87.4 ± 3.7	$85.4 \pm 3.0^*$	85.8 ± 3.1
MCH (pg)	29.5 ± 1.5	29.6 ± 1.4	29.7 ± 1.2
MCHC (g.L^{-1})	33.8 ± 0.8	$34.6 \pm 1.0^{**}$	34.6 ± 0.8
RDW-CV(%)	12.6 ± 0.8	12.7 ± 0.8	$12.3 \pm 0.5^*$
PLT ($10^9.\text{L}^{-1}$)	227 ± 33	238 ± 46	249 ± 49
WBC ($10^9.\text{L}^{-1}$)	5.63 ± 0.90	$6.95 \pm 1.79^{**}$	6.34 ± 1.26
Neutrophils ($10^9.\text{L}^{-1}$)	3.40 ± 0.88	$4.46 \pm 1.66^{**}$	$3.61 \pm 1.13^*$
Lymphocytes ($10^9.\text{L}^{-1}$)	1.66 ± 0.22	1.73 ± 0.55	$1.98 \pm 0.31^*$
Monocytes ($10^9.\text{L}^{-1}$)	0.42 ± 0.10	$0.54 \pm 0.31^{**}$	0.55 ± 0.18
Eosinophils ($10^9.\text{L}^{-1}$)	0.14 ± 0.12	$0.20 \pm 0.13^*$	0.18 ± 0.15
Basophils ($10^9.\text{L}^{-1}$)	0.015 ± 0.009	0.017 ± 0.011	0.019 ± 0.013

Sat, saturation; RBC, red blood cell; Hb, haemoglobin; Hct, haematocrit; MCV, mean cell volume; MCH, mean corpuscular haemoglobin; MCHC, mean corpuscular haemoglobin concentration; RDW-CV, red blood cell distribution width; PLT, platelets; WBC, white blood cell. Small (*) and moderate (**) between-subject differences from pre- to mid-season, and mid- to end-season are presented.

At each time point ~10-30% of female players had a ferritin concentration $<30 \mu\text{g.L}^{-1}$. Athletes with ferritin $<30 \mu\text{g.L}^{-1}$ were referred to the team physician and sports dietitian, prescribed oral iron supplementation, and received individualised nutrition counselling to address dietary iron intake. Over the season, seven female players (23%) received a 30-day course of iron supplementation (Ferro-grad C™, 105 mg elemental iron, 500 mg ascorbic acid), as determined by the team physician. Five cases of supplementation occurred following mid-season testing. Three players who required iron supplementation were currently using an oral contraception.

Across all female players tested, 50% were using oral contraception during the competitive season. The most common type of oral contraceptive used was a monophasic pill that contained low doses of levonorgestrel and ethinyloestradiol. There was no clear difference between ferritin values for oral contraception users and non-users ($-0.29, \pm 0.59$). The mean daily iron intake for the subset of seven female players was 13.9 ± 3.7 mg. There was an unclear correlation between pre-season ferritin concentration and dietary iron intake ($r = 0.06 \pm \sim 0.65$; r -value $\pm 90\%$ CL). A large positive correlation was found between age and pre-season ferritin concentration for females ($r = 0.66 \pm \sim 0.33$), but not males ($r = 0.20 \pm \sim 0.45$).

When divided into “low” and “high” playing load groups based on the number of international tournaments players participated in, females who competed in 4-5 tournaments had lower ferritin concentrations (48%, $\pm 66\%$; mean difference, $\pm 90\%$ CL) compared to those competing in <4 tournaments. Conversely, men who played in 2-9 tournaments had a slightly higher ferritin concentration at end-season (17%, $\pm 18\%$) than those who competed in one or none.

Discussion

Over an international rugby sevens season the majority of haematological parameters stay within the normal athlete range for male and female players with only minor fluctuations. On average, males had three-fold higher ferritin concentration than females, even when normalised for body mass. Ferritin concentration was lowest for both groups mid-season when training/competition demands, travel and possibly altered food availability were combined. For females, these demands, and the possible influence of low dietary iron intake

and/or menstrual losses, resulted in up to 30% of players classified as iron deficient at any time point. Regular haematological monitoring of female rugby sevens players would inform overall health and physical preparations for training and competition.

While no athlete in this study was classified as clinically anaemic, >30% of female players were iron deficient (ferritin $<30 \mu\text{g.L}^{-1}$) at each time-point and required supplementation. If the threshold of $<35 \mu\text{g.L}^{-1}$ was applied some 25-50% would be classified as iron deficient and all but two individuals would be considered functionally iron deficient (ferritin 30-99 $\mu\text{g.L}^{-1}$). While the Australian Institute of Sport laboratory reference range (1) for ferritin (Figure 1) is specific to the athletic population (mean and 95% CI), clinicians must determine whether supplementation is required. The decline in ferritin concentration mid-season (~20%, male and female players) is similar to reports in professional male soccer (142) and rugby union (17) players. Despite this, ferritin concentration in male players remained within a normal range. The small decline mid-season for female players, however, proved to be an issue given low pre-season values. Mid-season testing had the greatest number (absolute and relative) of players classified as iron deficient, requiring iron supplementation. Fluctuations in ferritin likely reflect periods of heavy training and competition loads (18), however, as training load was not monitored during the season this is only speculative. Potentially, there is a lag between periods of high training loads and haematological changes and may explain, in part, the decline observed mid-season, following pre-season training. The slight rise end-season, then, may be a result of training load stabilisation mid-season with partial recovery from pre-season training.

Despite a paucity of information available on the tracking of haematological variables across a season in female team-sport athletes, single time-point studies report a slightly higher (50%) (45, 165) incidence of iron deficiency compared to our study (30%). While the heavy contact nature of rugby sevens can result in marked muscle damage and haemolysis in female players (26), this did not appear to negatively influence the iron stores of players beyond that reported elsewhere. However, given the decline in ferritin mid-season (men and women), longitudinal monitoring of rugby players (particularly females) enables a better understanding of the relationship between iron status, training loads and dietary intake throughout a season. While a decline in ferritin may not always result in iron deficiency, iron storage can be altered in female athletes (10-15% lower serum iron and transferrin saturation, 10% higher soluble transferrin receptor), compared to non-athletes

(45). While male and female players experienced minor reductions in ferritin concentration mid-season, the initial low values in females suggest pre- and mid-season testing for this group should be considered. Other unique factors (menstruation, oral contraception use and dietary intake) may also be required to consider when managing iron status in female rugby sevens players.

In this study, oral contraception had an unclear influence on the prevalence of iron deficiency in female players. While heavy menstrual blood loss can lower ferritin levels (200), oral contraceptives can limit the amount of blood lost during menses (99, 115), and indirectly help elevate ferritin levels. However, this was not measured in our study. It is possible that the small sample of female players in this study were not typically heavy menstrual bleeders, or may have had a menstrual dysfunction, and so the potential positive effects of using an oral contraceptive for this group were not illustrated. Instead, the low ferritin values observed in female players, both users and non-users of oral contraception, are presumably related to low dietary intake and/or a high turnover of red blood cells.

Iron intake in the small subset of female players at pre-season showed the mean intake ($13.9 \text{ mg}\cdot\text{d}^{-1}$) was below the recommended dietary intake for females (RDI, $18 \text{ mg}\cdot\text{d}^{-1}$) but above the estimated average requirement (EAR, $8 \text{ mg}\cdot\text{d}^{-1}$) (22). The EAR is the amount of a nutrient estimated to meet the requirements of half the population (median usual intake), whereas the RDI accounts for 98% of the healthy age- and sex-specific population. Female athletes from varied sport backgrounds report a similar mean intake ($13.8 \text{ mg}\cdot\text{d}^{-1}$) (110). However, 60% of athletes were classified iron deficient (ferritin $<35 \mu\text{g}\cdot\text{L}^{-1}$) (110). It appears many female athletes consume less than the RDI of iron, independent of their sport. In combination with appropriate dietary intake, timing of consumption must also be considered. Given hepcidin is released following exercise and inhibits the absorption of iron (144), athlete's should be counselled about dietary sources of iron and appropriate timing of intake.

Previous research shows young (<18 years) male and female athletes at greater risk of iron deficiency (110). While there was an unclear correlation between ferritin concentration and age in males, a large positive correlation was apparent for females in our study. Young players, and those new to a full-time program, may be at greater risk due to an increase in training demands, new living arrangements, and/or having little previous nutrition

education. Coupled with blood profiling at the beginning of a competitive season (59), players should consult a sports dietitian for a dietary review to ensure appropriate and timely intake of macro- and micro-nutrients essential for general health and training adaptations (54).

Highly aerobic-based sports such as cycling, running and swimming have reported 4-12% reductions in athletes' Hb, Hct and reticulocytes over a competitive season (15, 133, 147). In men's rugby union (17) and soccer (123, 142), Hb declined by ~2-3% (or ~0.30-0.45 g.dL⁻¹ from a mean value of 15 g.dL⁻¹) over a season, similar to that reported here. Greater volumes of endurance-type exercise results in greater reductions in Hb and Hct over a competitive season (18). Given the aerobic component of rugby sevens is lower than in endurance-based sports, smaller changes in haematological variables were observed. The small fluctuations observed are likely a result of physiological variability and are unlikely to affect player health or performance. While some tournaments are paired over two subsequent weekends for the men's World Series, both the men's and women's competitions typically have a 4-6 week period between tournaments. This pattern of competition, while different to the weekly format of rugby union and soccer, appears to result in similarly small disturbances to haematological (Hb and Hct) variables. Although there was substantial movement in inflammatory markers mid-season for females (Table 8.2), all values remained within a normal range and were not likely of clinically significance. The use of non-steroidal anti-inflammatory drugs (NSAIDs) has been shown to inhibit the positive erythropoietic response (198) to training. Over a competitive season the use of these drugs may change (not measured) and should be considered in future studies.

Conclusion

We recommend haematological testing for female rugby sevens athletes be conducted pre-season and mid-season, given the likelihood of initial low ferritin concentrations with the potential for further decline mid-season. Males may benefit from initial screening, with follow-up only when clinically indicated (59). A multi-facted approach should be used to monitor and manage players, including focussing on adequate dietary intake and athletes who are young or new to a full-time training program.

CHAPTER NINE

General Discussion

Summary of Findings

The results within this thesis now enable a more specialised, tailored approach for female rugby sevens players before, during and after games, tournaments and a competitive season. A total of six laboratory- and field-based studies of physical and performance characteristics of rugby sevens players were completed within this thesis. The game demands, physical characteristics and anthropometric profiles of male and female rugby sevens players across three levels of competition were quantified (*Chapter Three*) to provide a detailed contemporary understanding of the demands of rugby sevens. The current use of microsensor technology to assess high speed running for female players (*Chapter Four*) and collision detection in rugby sevens (*Chapter Five*) were then evaluated before exploring the typical degree of neuromuscular fatigue, muscle damage (*Chapter Six*) and inflammation (*Chapter Seven*) associated with a women's rugby sevens tournament. The final study tracked players over a competitive season to quantify the incidence of iron deficiency in female rugby sevens players (*Chapter Eight*). A summary outlining the application of this body of research is provided in Table 9.1. The collective outcomes of this thesis span four key areas: monitoring female rugby sevens players; development and progression in women's rugby sevens; training and recovery for rugby sevens; and, microtechnology use in rugby sevens.

Table 9.1. Summary of thesis outcomes that can be applied to the management and monitoring of women's rugby sevens players, before and throughout a competitive season.

Pre-Season	In-Season
<ul style="list-style-type: none"> • Haematological monitoring of iron stores and contact with a dietician to assist with appropriate dietary intakes. If ferritin $<30 \mu\text{g.L}^{-1}$ consider supplementation. • Where possible, have a dietician available for players new to a full-time program or recently moved away from home. • Assess high-intensity running demands using the speed threshold of 3.5 m.s^{-1}. • Perform baseline physical and anthropometric testing of general fitness characteristics to monitor progression of training, and for talent identification of new athletes. • For Australian coaches, consult reference values (Table 3.1) for to evaluate player progression to elite performance characteristics. • Training should focus on improving general physical fitness (aerobic, speed, power and strength characteristics) given the strong correlations to game performance. • Inclusion of high-intensity running and collision drills to increase familiarity to the demands of rugby sevens games. • Development of rugby-specific skills is required, given limited background experience in collision-based sports. 	<ul style="list-style-type: none"> • Haematological monitoring of iron stores and contact with a dietician to assist with appropriate dietary intakes. If ferritin $<30 \mu\text{g.L}^{-1}$ consider supplementation. • Assess high-intensity running demands using the speed threshold of 3.5 m.s^{-1}. • Discontinue use of GPS-derived relative total running distance as a performance metric and apply caution if using GPS-derived collision data. • Continually develop rugby-specific skills, given limited background experience in collision-based sports. • Training should also include substantial amounts of high intensity running and collision drills to maintain fitness and familiarity with the demands of rugby sevens competition. • Recovery interventions should be based on total game time or game movement patterns for elite level players. Players at lower levels of competition should have additional recovery time given typically greater disturbances due to a tournament.

Monitoring female rugby sevens players

Two areas where the monitoring of players needs to be adopted for female rugby sevens players are the assessment of high intensity running demands and monitoring of iron stores to reduce the incidence of iron deficiency in players. Previous research studies in women's rugby sevens have used 5 m.s^{-1} (148, 175) and 4.4 m.s^{-1} (194) as thresholds for high intensity running, similar to that used in men's rugby sevens (5 m.s^{-1}) (82, 90, 162, 173). However, a threshold of 5 m.s^{-1} underestimates high-intensity running by up to 30% in

female rugby sevens players and is biased towards players in the team who are typically sprinters (*Chapter Four*). Instead, a physiologically-defined threshold of $3.5 \text{ m}\cdot\text{s}^{-1}$ is more appropriate for assessing high-intensity running in female rugby sevens players. Coaching staff can immediately implement the speed threshold of $3.5 \text{ m}\cdot\text{s}^{-1}$ within their game and training GPS monitoring programs. Not only does this information allow for a more accurate understanding of the game demands in women's rugby sevens, but it also permits the appropriate evaluation of individual player loads in training and competition without favouring the workloads of players who are sprinters.

In a traditionally male dominated sport, health issues that are typically female-specific, such as iron deficiency, are of little concern. However, at key points within a season up to 30% of female players have low iron stores (*Chapter Eight*), and may benefit from iron supplementation. While more established (international) teams are likely to have access to a team dietician, this service is often not available to other programs, teams and players. Highlighting this potential issue can assist female rugby sevens players to maintain optimal performance and recovery. Table 9.2 has been devised to quickly determine players at increased risk of iron deficiency, along with recommendations for regular haematological testing. The lower reported ferritin of young players and new recruits to a full-time program is important given the current practice where some young players are fast-tracked into programs and international representation. Around the world more teams are now implementing full-time programs, and for some individual players this means their first move away from home. At such an important period in their lives, these players now have responsibility for their own food choices, often with limited nutritional knowledge, coupled with a likely increase in weekly training loads. A substantial association between the use of oral contraception and maintenance of iron stores was not demonstrated in female rugby sevens players in this thesis. However, the practical benefits of manipulating the menstrual cycle to avoid the withdrawal (bleeding) phase during intensive training periods, or for hygienic considerations while travelling overseas, would be welcomed by many female players. A holistic approach that includes regular haematological monitoring, close contact with a team dietician, and exploration of oral contraception for both health and personal comfort reasons, is recommended for female rugby sevens players.

Table 9.2. Scoring system to identify the risk of developing iron deficiency during a rugby sevens season.

Question	Answer	Points
What is the athletes' sex?	Male	0
	Female	2
What is the athletes' age range?	>25 yrs	0
	18 – 25 yrs	1
	<18 yrs	2
Years within a full-time training program?	>2 yrs	0
	1 – 2 yrs	1
	<1 yr	2
What phase of the competitive season is it?	Pre-season	1
	Mid-season	2
	End-season	0

0 – 2 points: Low Risk. Pre-season testing may be beneficial to obtain a baseline measure. Follow up testing should only be undertaken if required.

3 – 5 points: Moderate Risk. Pre-season testing is likely beneficial for this group, especially for players who are young or new to a full-time program. Mid-season testing may be required for athletes who have low-to moderate ferritin concentration pre-season, or who are reporting feelings of fatigue and/or have nutritional concerns.

6 – 8 points: High Risk. Pre-season testing is required for this group with follow up testing completed six months later to coincide with mid-season. This group mostly contains female players who are also young or new to a full-time program. Close consultation with a dietician is recommended for this group.

Player development and progression in women's rugby sevens

Opportunities for females to play a contact sport such as rugby sevens have historically been limited. However, the inclusion of rugby sevens in the Olympic Games from 2016 is increasing the awareness and accessibility of the sport to females around the world. A large performance gap is evident between playing levels that is not apparent in the men's game (*Chapter Three*). Anecdotally, many young female players are turning to the sport from non-rugby sporting backgrounds. Consequently, there is a large learning curve to understand the specifics of the sport and become familiar with the level of contact required. Until now, no research has focussed on junior female rugby sevens players, and little research differentiates playing levels (194) and selected and non-selected players (79). Outcomes from this thesis indicate that well-developed physical and anthropometric characteristics have a positive relationship with the game movements of players (*Chapter Three*), and may also attenuate muscle damage resulting from a rugby sevens tournament (*Chapter Six*). A key focus of training should be developing aerobic endurance, speed, and

power – a combination of attributes unique to rugby sevens that can be difficult to train simultaneously. Adequate inclusion of contact sessions will also allow players to become familiar with the physical demands of the sport, develop appropriate tackling technique for safety, and limit the physiological disturbance resulting from competitive games.

Understanding the current game and physical profiles of female rugby sevens players allows for directed talent identification and selection processes. However, moving forward, the continual exposure to the sport will likely increase the demand for more technically and tactically skilful players. Knowing the physical characteristics of elite female rugby sevens players highlights key desirable player attributes (speed, power, endurance) and can direct selection and identification of players for possible future national representation. While players' are required to understand rugby specific elements of the game, the greatest improvements in the women's game currently will be achieved via developments of their physical and anthropometric profiles, with top performing women's teams more physically dominant than developing teams (*Chapter 2*, Table 2.4). For example, desirable qualities of top-level successful female players include a well-developed aerobic capacity, speed and power characteristics, and a favourable anthropometric profile (with a high proportion of lean muscle mass) (*Chapter 3*). It is reasonable to speculate, however, that as elite female programs become more established worldwide the physical and anthropometric characteristics of these teams will become more homogeneous, as has occurred in men's rugby sevens (161, 162, 179, 203). If this is the case, superior rugby tactical and technical elements will likely differentiate top-level female teams in the future and will be seen through the different styles of play and game running movements employed. Further, having established developmental differences between teams at the various levels of female rugby sevens competitions (junior, senior, elite) in Australia (*Chapter 3*), it is now possible to develop talent identification criteria and specialised training programs that identify and optimise anthropometric and physical characteristics of players, technical/tactical ability and game performance metrics. While physical and anthropometric characteristics are good discriminators of playing level and likely success in women's rugby sevens, a more complex mix of parameters will be needed at all levels of competition in the future.

Training and recovery for rugby sevens

Quantifying the game movements at specific levels of competition increases the understanding of the physical requirements of players, and as such can be used to direct the prescription of conditioning programs. The mean total distance, relative running distance, proportion of high speed running and the number and duration of sprints reported in *Chapter Three* can be used to prescribe fitness programs for both male and female rugby sevens players. This is the first study to provide the anthropometric and physical characteristics together with game running movements of male and female rugby sevens players across all three (Junior, Senior and Elite) levels of competition. Given players at lower levels of competitions are less fit and seemingly more prone to muscle damage following tournaments (*Chapter Six*), emphasis on developing physical qualities is highly desirable to maintain performance, and limit the physiological disturbances during a rugby sevens tournament. Training that includes adequate high speed running efforts and collision events should familiarise players to the demands of rugby sevens competition. Given muscle damage is the result of both metabolic (running movements) and mechanical (physical collisions) factors, conditioning programs that include tackle-like events, either through wrestling with another player or a tackle simulation with tackle bags, in combination with high intensity running, would be beneficial for players. Such information is of immediate use to strength and conditioning staff as they program relevant and appropriate conditioning programs for rugby sevens players.

Only two studies have examined the physiological disturbances that occur following a men's rugby sevens game (179) and tournament (203). However, players were not followed between consecutive tournament days, or in the days following the completion of the tournament. On this basis, there are few evidence-based recommendations on the time course and recovery period required for players following a rugby sevens tournament. Taking the player analysis (*Chapter Three*) and tournament studies (*Chapter Six and Seven*) together, it appears that player competition level and fitness, as well as overall playing time, influence the physiological disturbance and inflammation that occurs following a women's rugby sevens tournament. Players who are relatively new to the sport, or those still developing their game fitness, may experience a greater physiological disturbance following tournaments. These types of athletes are more prevalent at junior or developing levels of competition. For coaches training these athletes, it is important to ensure adequate

recovery is provided following tournaments before subsequent training sessions, especially given other stressors or demands that may also affect the ability to recover (i.e. school, recently moved away from home for the first time, other sporting commitments and, potentially, work commitments). Within an elite environment it is assumed that all players are familiar with the demands of the sport, have adequate fitness to cope with these demands, and access and time to complete appropriate recovery interventions. For this group, coaches should be implementing recovery protocols based on the total game time that players are involved in, allowing an individualised approach to recovery.

Microtechnology use in rugby sevens

Until now, some microsensor technology metrics to assess player movements have been employed with little consideration of their appropriateness or utility for rugby sevens. The series of studies in this thesis have identified a more appropriate threshold of high-intensity running for female players (*Chapter Four*), and shown the limitations of using both relative total running distance to differentiate playing levels (*Chapter Three*) and automated collision detection technology (*Chapter Five*) in rugby sevens. While consistent with previous literature (90, 161), no discussion over the efficacy of relative total running distance to discriminate rugby sevens performance has been considered previously. Given this measure appears to lack the sensitivity required to differentiate playing levels, assessing individual player performance, regardless of playing level, based on relative total running distance is inappropriate. Instead, alternative measures including relative running distance at peak periods in the game or metabolic power should provide more meaningful information to coaching staff. Similarly, given collision events are incorrectly recorded 45-60% of the time in men's and women's rugby sevens (*Chapter Five*), using microtechnology for this purpose is not recommended. While it is a desirable metric that warrants further investigation, information around the number and severity of collisions in rugby sevens will have to be obtained from analysis of video-based coding until automated systems are improved.

Conclusion

The outcomes from this thesis centre on sex-specific monitoring and management of female rugby sevens players for assessing game performance, training monitoring, and general

health. In summary, women's rugby sevens programs will benefit from: using a female-specific GPS threshold of $3.5 \text{ m}\cdot\text{s}^{-1}$ to measure high-intensity running; implementing bi-annual (every six months) haematological monitoring of iron stores; performing targeted recovery interventions based on total playing time or game movements following a tournament; and, focussing training on developing a well-developed physical and anthropometric profile while increasing players' familiarity to high-speed running and collisions. Current microsensor technology is also not recommended for the automated detection of collisions in rugby sevens, and reliance on video-based notational analysis remains.

CHAPTER TEN

Practical Applications and Future Directions

Practical Applications

A number of key practical applications arise from the research outcomes presented in this thesis. While some have immediate application, others involve longer term considerations that apply to the development of programs and talent identification of players.

- Training conditioning programs can be developed based on running movements (total distance, percentage of high intensity running, number and distance of sprinting efforts, and collision frequency) according to an individuals' sex and playing level. For those players wishing to advance to higher levels of competition, conditioning programs progressing towards the game demands at an elite level will be advantageous.
- The physical and anthropometric characteristics of male and female rugby sevens players at both elite and developing levels can be used to benchmark players for selection and talent identification purposes. Female players with generally well-developed aerobic capacity, speed, and power will typically have enhanced game movement patterns.
- Training should focus on improving players' aerobic, speed, and power characteristics. Players should complete substantial running movements at high-speed ($>5 \text{ m}\cdot\text{s}^{-1}$) and collision/wrestling-based movements to increase familiarity with the demands of rugby sevens competition and reduce physiological disturbances associated with a two-day tournament.
- High intensity running should be evaluated using the speed threshold of $3.5 \text{ m}\cdot\text{s}^{-1}$ in female rugby sevens players. While the use of this threshold is not as sensitive as an individualised threshold, it permits comparison between players, sports, and seasons.
- Recovery protocols can be prescribed based on individual player fitness and familiarity with rugby sevens at sub-elite levels, and on the game playing duration for elite-level players. In the absence of specific recovery interventions within a rugby sevens tournament, a semi-individualised approach based on playing level, fitness and familiarity, and total playing time should be applied.
- Haematological monitor of players' iron stores should be completed on a six-monthly basis for female rugby sevens players, and yearly for male players. Pre-season testing

of all players allows potential at-risk players to be identified early. Subsequent testing, corresponding to the middle of the competitive season, is also recommended for female players, given the potential for iron stores to be reduced by this time. Consultation with a team dietician should be considered to provide a holistic approach to managing this potential issue, especially for female and young incoming players.

Limitations and delimitations

While the findings of this thesis have direct and applied outcomes for improving the management of women's rugby sevens players' health and physical development, assessment of game and training demands, and prescription of training and talent identification processes, some limitations and delimitations should be declared.

Limitations

Across all studies completed within this thesis there were elements where the availability of players impacted on the total number of players tested and timing of tests completed. Similarly, given injuries sustained during training and/or competition, the sample size of studies was affected as a result. While in some cases an injury resulted in players no longer being able to compete in games or undertake testing, some players continued on following an injury and, instead, managed their injury through strapping or the ingestion of NSAIDs. As a result of these injuries or discomfort, their game movements or post-tournament measures (*Chapter Six and Seven*) may have been impacted. However, these injuries are common in rugby sevens and a player's decision to play, train or test is determined on a case-by-case basis in consultation with the physiotherapist. As such, the results obtained in these studies are typical of real-world situations.

Variable field and weather conditions are also a limitation to studies in this thesis. Particularly, this was the case in *Chapter Three*, where multiple teams completed physical testing on varying surfaces and in different environmental conditions. While effort was taken to ensure the best surface and conditions were available during testing, inherent variations in weather conditions were not reported nor controlled.

In *Chapters Six to Eight*, all blood haematological and biochemical variables may be influenced by the phase of the menstrual cycle players were currently within. As it was beyond the scope of the studies to include testing of serum estrogen concentration, it is assumed that the values reported, and any changes that occurred, were evened out across all players. Despite this, the result still provide sound initial information on female rugby sevens players and the typical results you would likely see within a playing group.

Delimitations

All studies completed as part of this thesis were obtained on players within Australia. Establishing normative values for male and female rugby sevens players across different competition levels worldwide was not possible given the possible variations from country to country. This scenario is of particular importance for developing players where the opportunities and pathways to playing rugby sevens for their country will differ widely between established and emerging rugby nations.

Given rugby sevens has only 12 players in a team, with squads generally including around 20 players, the sample size of studies is limited in most rugby sevens research. While sample size was increased by following multiple teams in each group in *Chapter Three*, only two games (one men's game, one women's) were observed in *Chapter Five*. While observing the ability of collision-detection technology in an applied setting is advantageous, further work is required within a controlled setting to understand in detail the abilities and shortfalls of this technology, and the way that different events, situations, or thresholds used can change the outcome. This information is required before further applied work is completed using this technology.

Given the need to access specialised, non-portable biochemical and haematological equipment to complete studies in *Chapter Six and Seven*, only a limited number of sampling points were collected on physiological and haematological measures following a women's rugby sevens tournament. Similarly, elite level players were only able to be assessed for physiological and haematological disturbances following a domestic tournament. Assessment at international level competitions has yet to be undertaken.

Future Directions

From the outcomes presented within this thesis a number of key areas for further research are identified. Assessment and analysis of technical and tactical elements of play, appropriate recovery interventions, and development and refinement of microsensor technology for rugby sevens would be beneficial for the practitioner to improve the development and management of female rugby sevens players.

- Future research that integrates physical, technical and tactical aspects of play will be beneficial. Development of an objective measuring tool to assess tackle technique and game tactical effectiveness is needed for tracking the progression of players beyond anthropometric and physical measures. Similarly, observation of game involvements such as, for example, defenders beaten, line breaks, and successful tackles, will provide a more holistic approach to the game demands of players beyond just simple running movements.
- Once a comprehensive description of the game running movements, player involvements, and sequences of play has been established in women's rugby sevens, the degree of association between these measures and successful performance can be established using a regression model. Observing the differences in the game play between successful and unsuccessful teams, selected and non-selected players, and different playing levels, can provide an accurate, objective assessment of an individual's game performance and likely potential for performance at a higher level. This information could also drive the tactics that teams deploy, depending on their opposition.
- Given that collision events contribute to muscle damage and have a high potential for injury, further information around this area is needed in rugby sevens. While microtechnology is currently available that allows for the automated detection of collisions, further refinement is required for rugby sevens. Measurement studies examining the criterion validity and test-retest reliability of both automated collision detection technology and the robust quantifying of impacts are required. Further consideration for female-specific assessment warrants investigation in these areas also.

- The current understanding of the magnitude and clinical/performance implications of physiological disturbances that typically occur following a rugby sevens tournament is limited. Moreover, the prescription of recovery practices has not been assessed critically for use in rugby sevens. Critical evaluation of the most appropriate recovery strategies between-games and between-days of competition will improve the management and recovery of players, while also making the most of available time and resources. Given the increase in back-to-back tournaments, recognising the time course for recovery from tournament-induced physiological disturbances is important for prescription of appropriate return-to-training activities and timelines. More comprehensively, observing patterns of change in blood parameters and neuromuscular fatigue at an elite level of competition will improve the management of players post-tournament and may limit the risk of overtraining injuries or illness.
- While relative total running distance is a poor measure for differentiating playing levels in rugby sevens, closer examination of changes occurring within peak and post-peak periods may improve the understanding of game demands. Further assessment of game movements may provide a better indication of the game demands and individual performance during a rugby sevens game, and over a tournament. Systematic monitoring of games and players would enable refinement of training to adequately prepare players for competition and individualise recovery protocols during- and post-tournament.

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APPENDICES

Appendix A (abstract) – Physiologically-based GPS speed zones for evaluating running demands in women's rugby sevens

Anthea C Clarke, Judith M Anson, David B Pyne

Sports Medicine Australia – Be Active Conference

Canberra, Australia

October, 2014

Introduction: Global positioning system (GPS) speed zone thresholds used to evaluate running demands in men's rugby sevens matches may not accurately reflect the player demands imposed during competitions on female rugby seven's players, especially at higher speeds. The aim of this study was to establish, for international female rugby seven's players, a physiologically-based speed threshold - the second ventilatory threshold (VT2) - for analysis of high speed running data captured by GPS units throughout a tournament. We then characterised the relationship between this estimate (the VT2) and the commonly used value of 5 m.s⁻¹ to individual players' VT2 and maximal running speed during games.

Methods: Seven international female players (22.4 ± 2.5 years, 1.69 ± 0.04 m, 68.5 ± 6.9 kg, 72.4 ± 11.5 mm sum of seven skinfolds) performed a VO₂ max test on a treadmill to estimate the mean speed at VT2. GPS data for 12 players was obtained during an international women's rugby sevens tournament (68 game files) and analysed using inferential statistics.

Results: The estimated mean speed at VT2 was 3.5 ± 0.3 m.s⁻¹. There was a large correlation between player's VT2 speed and distances covered above the 3.5 m.s⁻¹ threshold, however, there was substantial uncertainty in this estimate (r=0.61, -0.11 – 0.91; 90% confidence interval). Distances covered above 5 m.s⁻¹ had a trivial correlation with VT2 (r=-0.03, -0.69 – 0.66). Maximal running speeds reached during games had a trivial correlation with distances covered above 3.5 m.s⁻¹ (r=-0.09, -0.72 – 0.63) but a very large correlation above 5 m.s⁻¹ (r=0.76, 0.17 – 0.95).

Discussion: In women, the distance covered above the VT2-determined threshold level of $3.5 \text{ m}\cdot\text{s}^{-1}$ reflects the anaerobic running component completed by players during games, whereas $5 \text{ m}\cdot\text{s}^{-1}$ better relates to players' maximal running ability. The threshold of $3.5 \text{ m}\cdot\text{s}^{-1}$ is a speed zone cut-off that better represents the demands of rugby sevens in female players. The new threshold could be useful in ensuring effective and efficient training, and reducing the risk of overtraining or fatigue-related injuries in women rugby sevens players, given a more accurate understanding of the physiological load on players in both training and competition settings.

Appendix B (abstract) - Neuromuscular fatigue and muscle damage in women's rugby sevens

Anthea C Clarke, Judith M Anson, David B Pyne

8th World Congress on Science and Football

Copenhagen, Denmark

May, 2015

Abstract

This study examined the relationships between on-field game movement patterns and changes in markers of neuromuscular fatigue and muscle damage during a two-day women's rugby sevens tournament. National (n=12, 22.3 ± 2.5 y, 1.67 ± 0.04 m, 65.8 ± 4.6 kg; mean ± SD) and State (n=10, 24.4 ± 4.3 y, 1.67 ± 0.03 m, 66.1 ± 7.9 kg) female representative players completed baseline testing for lower-body neuromuscular function (CMJ test), a muscle damage marker (capillary creatine kinase (CK)), perceived soreness and perceived recovery. Testing was repeated after games on days one and two of the tournament. GPS (5 Hz) data were collected throughout the tournament (4-6 games per player). National players were involved in small to moderately greater on-field movements for total time, distance, high speed running (>5 m·s⁻¹), and impacts >10g (effect size (ES) = 0.55-0.97), and displayed a smaller decrement in performance from day one to day two. Despite this, State players' had a much greater (ES=0.73) 4-fold increase in CK compared to the 2-fold increase in National players. Both groups had similar perceived soreness and perceived recovery while CMJ performance did not change. High-speed running and impacts >10g were largely correlated (r=0.66-0.91, ~±0.30 90% confidence limits) with ΔCK for both State and National players. A two-day women's rugby sevens tournament elicits substantial muscle damage, however, there was little change in lower-body neuromuscular function. Modest increases in CK can largely be attributed to the amount of high-speed running and the number of impacts >10g that players endure.

Appendix C (abstract) – Monitoring iron levels in male and female rugby sevens players over an international season

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American College of Sports Medicine 63rd Annual Meeting

Boston, USA

May, 2016

Abstract

PURPOSE: Given the likely influence that high training loads, contact-induced hemolysis and female-specific requirements have on the incidence of iron deficiency, characterizing the direction and magnitude of fluctuations in iron status over an international season is important for managing player health and physical performance in rugby sevens. **METHODS:** Australian national male (n=27) and female (n=23) rugby sevens players undertook blood tests at pre-season, mid-season, and end-season. Hemoglobin, haematocrit, ferritin, transferrin and transferrin saturation were quantified. Female athletes also reported oral contraceptive use and a subset (n=7) provided 7-day food diaries to quantify iron intake. **RESULTS:** Male players typically had a three-fold higher ferritin concentration than females. Pre-season ferritin concentrations in male ($151 \pm 66 \mu\text{g/L}$; mean \pm SD) and female ($51 \pm 24 \mu\text{g/L}$) players declined substantially (~20%) by mid-season, but recovered by end-season. Over the season, 23% of female players were classified as iron deficient (ferritin $<30 \mu\text{g/L}$) and prescribed supplementation. The greatest incidence of iron deficiency in female players occurred mid-season (30%). Oral contraception and dietary iron intake had an unclear influence on female players' ferritin concentration. All other haematological variables were within normal physiological range. **CONCLUSION:** Given the relatively low ferritin concentrations evident in female rugby sevens players, and the potential for further decline midway through the season when physical load is highest, 6-monthly haematological reviews are suggested in combination with dietary management. Annual screening may be beneficial for male players, with further monitoring only when clinically indicated.