

The Relationship between Physical Qualities and Activity Profiles of International Women's Sevens Players

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This thesis is submitted in accordance with the requirements of The Graduate Research Office, Australian Catholic University for the degree of Doctor of Philosophy by Tyler Goodale.

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Declaration

This thesis contains no material published elsewhere or extracted in whole or in part from a thesis by which I have qualified for or been awarded another degree or diploma. No parts of this thesis have been submitted towards the award of any other degree or diploma in any other tertiary institution. No other person's work has been used without due acknowledgment in the main text of the thesis. All research procedures reported in the thesis received the approval of the relevant Ethics/Safety Committees (where required).



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If I have seen further than others, it is by standing upon the shoulders of giants.

Abstract

Due to its inclusion in the recent Olympic Games, women's Rugby Sevens has experienced a marked increase in popularity. As a result of the sports' emergent nature the player profile and performance demands of women's Rugby Sevens remain poorly understood.

Rugby Sevens is a modified game of 15-a-side Rugby Union, played under similar laws but with fewer players per side and for less total game time. The sport is played in a tournament format with multiple games played in one day and across a 2 to 3-day period. Rugby Sevens is one of the few true contact sports played by females and is therefore unique in this regard.

A lack of research into the specific demands of the game and physical qualities of the players means that the majority of training decisions for the sport are based on research performed on males playing either Rugby Sevens or other Rugby codes. As sex differences specific to elite sport performance are known to exist, basing training prescriptions for females on male-specific research requires a number of assumptions to be made, which is unfair and potentially inappropriate to female athletes of any playing ability.

Based on the identified gaps in the literature, the purpose of this thesis was to first characterize 1) the physical qualities of players; and 2) the game demands of international women's Rugby Sevens; and 3) to then examine the interaction between these aspects of the game. To achieve these aims, it was important in Study 1 to first identify physical qualities that discriminated playing rank in women's Rugby Sevens. Then, in Study 2, the characteristics of game activity and physiological

demands of international women's Rugby Sevens were profiled and further investigated for how these demands changed in relation to key contextual factors such as: game half, game outcome, game margin, tournament day and playing position. Study 3 examined game demands in further detail specifically relating to the tactical phases of play; attack and defense. The interaction between tactical phase demands and game outcome was examined in order to profile successful style of play. Finally, Study 4 examined the relationships among physical qualities, game demands and contextual factors with the aim of identifying the physical qualities important for success at the international level.

The international game of women's Rugby Sevens is a physically demanding game, requiring athletes to run at and maintain high-speeds while under significant physiological strain. High-speed running ability across games and relative to minutes played was positively related to a number of contextual factors including game half, game outcome, game margin and opponent rank. High-speed running demands were consistently greater in defense than attack. To support the demands of the international game, women's Rugby Sevens players are required to have well-developed strength, aerobic fitness, speed and repeated-sprint abilities. The development of these physical qualities, which were also found to underpin in-game activity and physiological profiles, will help to support successful game outcomes.

Collectively, this thesis has provided a foundation and pragmatic level of knowledge on elite performance in women's Rugby Sevens. Specifically, the development of physical qualities that support high-speed running ability may best prepare and maintain women for international-level competition in Rugby Sevens.

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Figure 7.1. The interaction between physical qualities, match activity profiles and contextual factors in international women's Rugby Sevens.

List of Abbreviations

%	Percent
~	Approximately
≥	Greater than or equal to
AU	Arbitrary units
AU·min ⁻¹	Arbitrary units per minute
beats·m ⁻¹	Beats per minute
bpm	Beats per minute
BRA	Brazil
CDN	Canada
CHN	China
CL	Confidence limit
cm	Centimetre
CS	Critical speed
<i>d</i>	Cohen's effect size statistic
ENG	England
ES	Effect size
F ₀	Theoretical maximal forces
FRA	France
g	Gravity
GPS	Global positioning system
HR	Heart rate

HRmax	Heart rate maximum
HSD	High-speed distance
Hz	Hertz
ICC	Intraclass correlation coefficient
ISM	Initial sprint momentum
kg	Kilogram
$\text{kg}\cdot\text{m}\cdot\text{s}^{-1}$	Kilogram per meter per second
$\text{kg}\cdot\text{kg}^{-1}$	Kilogram per kilogram
Km	Kilometre
$\text{km}\cdot\text{hr}^{-1}$	Kilometre per hour
LB	Lower-body
m	Meters
$\text{m}\cdot\text{min}^{-1}$	Meters per minute
$\text{m}\cdot\text{s}^{-1}$	Meters per second
min	Minute
$\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$	Millilitres per kilogram per minute
mm	Millimetre
$\text{mmol}\cdot\text{L}^{-1}$	Millimole per litre
MSM	Maximal sprint momentum
n	Number
$\text{N}\cdot\text{kg}^{-1}$	Newtons per kilogram
NED	Netherlands

NTC	National training centre
$\dot{V}O_{2max}$	Maximal aerobic power
p	Probability
PL	Player load
Pmax	Maximal power
r	Pearson product correlation
RM	Repetition maximum
r_s	Spearman rank correlation
RSA	Repeated-sprint ability
s	Second
SAS	Statistical analysis system
SD	Standard deviation
SLJ	Standing long jump
STJ	Standing triple jump
tackles.min ⁻¹	Tackles per minute
UAE	United Arab Emirates
UB	Upper-body
USA	United States of America
V_0	Theoretical maximal velocities
$v \dot{V}O_{2max}$	Velocity at maximal aerobic power
W.kg ⁻¹	Watts per kilogram
WSWS	Women's Sevens World Series

Yo-Yo IR1 Yo-yo intermittent recovery level 1

Navigation of the Thesis

Understanding the demands of women's Rugby Sevens is important to inform training decisions around the preparation of both the team and athletes participating in the sport. This thesis assessed the game demands of women's Rugby Sevens by first identifying the knowledge gaps in this area existing within the literature and then by applying a series of studies designed to assess the athlete, the game and the interaction between these components at the elite level.

Through a narrative review of the literature, Chapter 2 identifies the current existing gaps in the body of knowledge specific to women's Rugby Sevens. These gaps in the literature were then strategically addressed with four experimental studies.

Chapter 3 addresses the physical qualities that differentiate playing rank in women's Rugby Sevens. With a better understanding of the physical characteristics of elite women's Rugby Sevens players, the demands of the international game were then examined, describing the general demands through microtechnology-derived game analysis, then tracking how these demands change; across the course of a game, over a tournament, between wins and losses, among positional groups, and opponent rank (Chapter 4).

Chapter 5, shows a closer investigation of the specific differences in game activity demands between tactical phases of play (attack and defense), and determines if these demands are influenced by game outcome. In the final experimental chapter (Chapter 6), the interactions between the individual variables from the preceding studies (game demands and player physical

qualities), and how these interact with game outcome and positional differences were examined. The final chapter of thesis (Chapter 7) provides a summary of the 4 experimental studies (Chapters 3, 4, 5, 6), offers practical applications based off experimental findings, identifies strengths and limitations of the collective studies within the thesis and suggests future Rugby Sevens research directions.

Chapter 1: General Introduction

1.1 Overview of Rugby Sevens

With its recent inclusion in the 2016 Olympic Games, Rugby Sevens is rapidly growing in popularity. Rugby Sevens made its debut on the international sport scene in 1976 in Hong Kong. The sport continued to develop over the next 17 years, and in 1993 the World Cup of Rugby Sevens was held. Since then, the sport has grown to include a 10 and 6 tournament World Series of Rugby for men and women, respectively. The men's series has been played since 1999 and the women's series was recently launched in 2012. Competitions are currently played at most international major games including the Olympics, Commonwealth and Pan-American Games.

Rugby Sevens is a variation of 15 a-side Rugby Union. The laws of the two games are similar but there are fewer players per side in the game of Sevens, and approximately 85% less total game time. Sevens is played on a full-sized Rugby pitch and games are comprised of two, seven minute halves separated by a two-minute half-time. Games are played in a tournament style, normally lasting over two to three days. Typically, teams play two to three games played per day, each separated by approximately three to four hours.

Since the announcement of Rugby Sevens' inclusion in the Olympic Games program, nations have started to invest heavily in their national programs. This investment has led to an urgency by national sport organizations for professionalization within their national training structures. Exponential increases in funding due to Olympic Game inclusions, and capacity of national

programs, have resulted in a rapid evolution in professionalism of both the men's and women's game.

1.2 Identifying the Problem

Both male and female Rugby Sevens is characterized by high physical demands relative to minutes of play (1-4). Running velocities, distances covered, number of accelerations, as well as work-to-rest ratios are greater than in other forms of Rugby (Union and League) with relative contact demands similar to Rugby League (5-7). Initially a large majority of the research on the demands of Rugby Sevens had been performed on men (1, 3, 8, 13, 14, 20-23) with limited research being performed on females, specifically at the elite level (9-11). It is important to have an understanding of the specific game demands at the top tier of play to better inform coaches, sport scientists and strength and conditioning coaches on how best to physically prepare players for competition.

Investigating the qualities that differentiate elite from sub-elite performers is important in order to: 1) identify the physical characteristics of elite athletes; 2) develop an understanding for player development pathways; and 3) understand the physical qualities to test in talent identification and transfer programs. To date, compared with the men's game (1, 3, 8, 13, 14, 20-23) very few investigations have been undertaken to identify the physical qualities of elite players in women's Rugby Sevens (10, 11, 16). Lacking a physical profile of elite women's Rugby Sevens affects the level of preparation that training programs are able to provide players. This can increase the risk of women's Rugby Sevens players being under-prepared for the game, increasing risk of under-performance and injury. Sevens' teams consist of twelve players; seven start the game, and five are replacement (bench) players. Given the brevity of the games, typically the same players start the majority of games as teams always aim to start each game with their strongest line up. This

results in an imbalance of playing minutes between players within a tournament. Players accumulating greater game time are exposed to a greater game load, with players accumulating the greatest game load typically the most accomplished players and critical to successful game outcomes. Due to the strategic advantage of finishing in a top position on day one, the availability of a team's top players can help to contribute to successful tournament finishes (Top three). If training decisions are not underpinned by scientific evidence or approaches, then the risk of not having the best players available (e.g. due to injuries or poor performance) for the course of a tournament or season increases; potentially reducing the probability of successful outcomes.

An understanding of the specific demands of the female game of Sevens is required as recent investigations comparing the men's and women's game of Sevens have already found significant differences exist in game speeds that represent high intensity running velocities. Specifically, women attain high-intensity running velocities at absolute speeds 30% lower than men (11). If similar velocities were used to compare demands of the men's and women's game, this would lead to an underestimation of the true relative physiological and movement demands of women's Sevens. Sex differences in running speeds and accelerations profiles also exist between male and female field hockey and soccer players (17, 18) providing further support for additional examination into women's Rugby Sevens. Investigating not only general game demands but those specific to tactical phase of play will support a more complete understanding of all aspects of Rugby Sevens. In this sport, players must play on both attack and defense. Knowing how tactical phase demands may vary between tactical phases will help improve the specificity of training, better preparing the athletes for the stresses placed upon them. In professional Rugby League, evidence has shown that the demands of attack and defense are unique to the specific tactical phase

of play (19). A better understanding of the difference in tactical play supports a more thorough training process.

Quantifying both the physical qualities of elite performers and the specific game demands imposed upon these players, allows the relationship between physical ability and game performance to be evaluated. To date, no study has investigated the relationship between the physical qualities of players and the movement demands of the game, in either male or female Rugby Sevens. This information will further elucidate which physical factors are of importance in supporting the athlete's ability to perform the demands of the game. A better understanding of the relationships between physical quality and game demands will thereby support both elite player development and inform training prescription and testing for players in the women's Rugby Sevens player pathway. Creating a foundational and pragmatic framework on the interaction between player physical qualities and specific game demands will support future investigations into other synergies within the game of Rugby Sevens.

To date, very little data have been published on Rugby Sevens, let alone female players (9, 10, 11). This thesis provides a unique opportunity to not only build a body of literature on the sport, but also add to the scientific knowledge on female field sport athletes. This improved knowledge on the unique aspects of the women's game will help guide coaches and practitioners on how to best prepare elite female players. By developing robust and validated player and game profiles, athletes will benefit from improved training prescription, helping them perform to their full potential. The unique opportunity to observe the sport as it develops across its first ever Olympic

quadrennial only comes along once in a sports history. Observing and investigating the sport and its athletes through this emergent phase will provide those involved with the sport a foundational level of shared and practical knowledge upon which to prepare teams and players at the top level. With strong dissemination strategies, the results from thesis can also provide support to identification and development of the sport as well as making a difference to players at the grass roots and developmental levels.

With this in mind, the purpose of this thesis is to examine:

- (i)* The physical qualities that discriminate elite and developmental performers in women's Sevens players (Study 1).
- (ii)* The activity and physiological profiles of the game at the top level of competition and how these profiles may be influenced by various contextual factors (Study 2).
- (iii)* The specific activity and physiological profiles of attack and defense and whether differences exist between phase of play profiles and game outcome (Study 3).
- (iv)* The relationship between physical qualities, game demands and contextual factors (Study 4).

Figure 1.1 outlines the workflow of the four experimental studies that comprise the thesis.

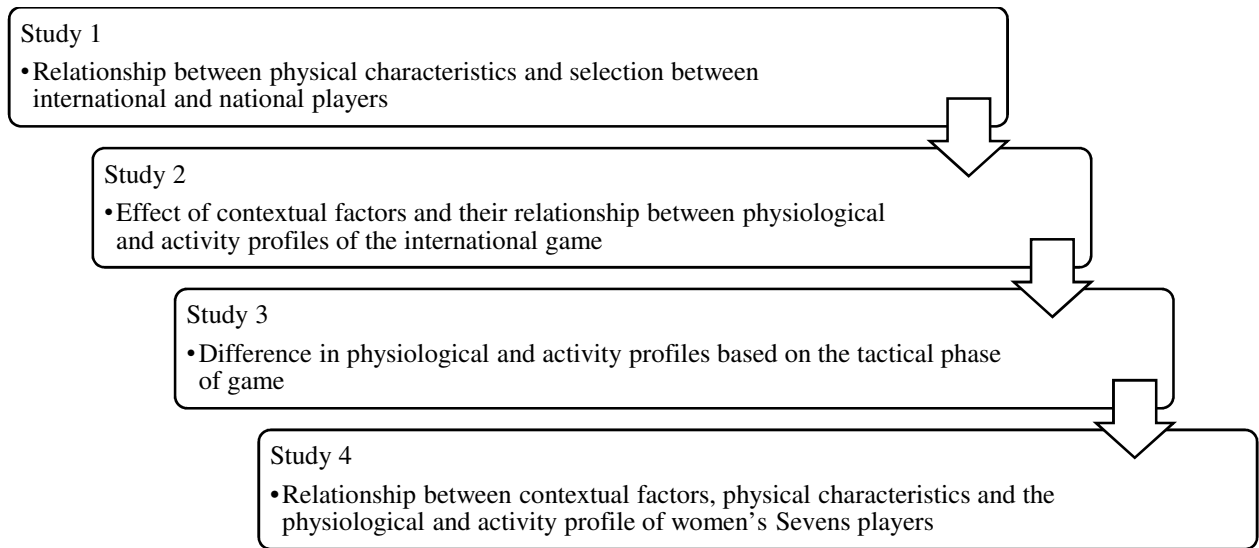


Figure 1.1. Workflow of thesis

Chapter 2: A Review of Match Demands and Player Physical Qualities in Rugby Sevens

Rugby Sevens is a collision based high-intensity intermittent team sport played internationally by both male and female athletes. Males participate in ten and females participate in six World Rugby international tournaments per year. Typically, tournaments take place across two to three days with each team playing two to three games played per day; games are separated by approximately two to four hours. A Sevens team is comprised of twelve players, seven of whom start leaving five players available for interchanges. Five total interchanges are allowed per game. ‘Starters’ are divided into forwards and backs; forwards are typically responsible for the set piece component of Rugby Sevens, the scrum and line out, with backs responsible for the majority of high-speed running elements of the game. Games are composed of two seven-minute halves with a two-minute half time.

2.1 Match Demands

Recent research has examined the game demands of Rugby Sevens in both male (1, 20-23) and female (2, 4, 10) players. Much of this research has examined both the movement and physiological demands of the sport, ranging from national to international competition in the men’s and women’s game. The details of existing knowledge of match demands are outlined in the following sections.

2.1.1 Match Demands – A Comparison between Men’s and Women’s Rugby Sevens

In the men’s game (Table 2.1), players have been found to cover total distances in the range of approximately 1200 to 2000 m, with relative demands for players completing full games ranging

between 85 to 120 m·min⁻¹ and substitutes covering between 100 to 140 m·min⁻¹. Approximately 80 to 200 m of the game is spent at high running speeds (≥ 5.0 m·s⁻¹) with a further 50 to 200 m covered while sprinting (≥ 6.5 m·s⁻¹) (1, 3, 13, 20, 22, 24). In men's Rugby Sevens running velocity zones have arbitrarily been established. Players achieve average top speeds ranging between 7.2 to 8.1 m·s⁻¹ while an average sprint will typically cover between 10 to 28 m, and maximum sprint distances range from 20 to 53 m (1, 13, 22).

The mean heart rate for a game ranges between 84 to 90% of maximum with peak heart rates of 95 to 99% of maximum occurring during the course of play. The majority of a game is played at 81 to 90% of maximum heart rate as players often achieve heart rates of greater than 80% of maximum within two minutes of game play (1, 13, 22).

Players are typically involved in 3 impacts (> 8 g) per minute with the average number of tackles ranging from 0.3 to 0.5 tackles·min⁻¹ of play (22). Although microtechnology 'impact and tackle' count monitoring has been reported in the literature, to date (2, 10, 22, 25), the reliability and validity of this practice remains controversial within Rugby Sevens (22, 25). Unlike in Rugby League (26), a lack of agreement prevails within Rugby Sevens between tackles and impacts recorded from microtechnology devices and those coded via notational analysis (22). In both the women's and men's game 62% and 45% of collisions, respectively have been labelled incorrectly via micro-technology devices (25). This indicates that further research and refinement into automatic collision and tackle detection from microtechnology devices for both men's and women's Rugby Sevens is required.

Table 2.1. Summary of studies on match demands in men's Rugby Sevens.

Study	Standard of Player	Participants (n)	Tournament Level	Tournament (n)	Main Findings
Higham et al. (2012) (1)	International	19	National and international	National: 3 International: 2	First study to report match demands for international caliber Rugby Sevens 50% greater relative demands for Rugby Sevens vs. 15-a-side Rugby Union International matches were physically more intense than national matches
Suarez-Arrones et al. (2012) (3)	National	7	National	1	Players were unable to maintain work rates between halves Rugby Sevens was characterized by high relative running demands with short recovery periods The relative running demands of Rugby Sevens were greater than other Rugby football codes
Granatelli et al. (2014) (27)	National	9	National	2	Minute-by-minute relative running demands demonstrated modulations in pace within game halves Rugby Sevens was metabolically demanding characterized by high mean heart rates >88% heart rate maximum and blood lactate concentrations >11 mmol·L ⁻¹ Match running demands varied between playing position (backs vs. forwards)

Study	Standard of Player	Participants (n)	Tournament Level	Tournament (n)	Main Findings
Suarez-Arrones et al. (2014) (22)	National	10	National	3	<p>Match running demands varied between playing position</p> <p>Backs covered more distance at higher running velocities than forwards</p> <p>Forwards were involved in more collisions than backs and experience greater heart rate responses</p> <p>Match running intensity decreased between halves</p> <p>Compared with video analysis Microtechnology did not precisely quantify physical collisions in Rugby Sevens</p>
Murray and Varley (2014) (28)	International	14	International	4	<p>Examining minute rolling peak running demands demonstrated 45-50% greater relative demands than traditional averaging of running demands across full run time analysis</p> <p>Match score, opposition rank and substitutions influenced the match demands of Rugby Sevens. Close games, opponents of higher rank and substitutions increased relative match demands</p> <p>Players were unable to maintain match activity profiles across halves</p>
Furlan et al. (2015) (29)	International	12	International	1	<p>Rugby Sevens was characterized by temporal variations in match activity and physiological profiles indicating some combination of fatigue and pacing existed within game halves</p> <p>Activity and physiological demands temporally varied relative to one another peaking at different times and demonstrating differing within game patterns</p>

Study	Standard of Player	Participants (n)	Tournament Level	Tournament (n)	Main Findings
Suarez-Arrones et al. (2016) (24)	International	12	International	2	<p>There was a substantial decrease in high-speed and repeated-high-speed activities between halves</p> <p>There was a substantial decrease in acceleration and deceleration events and repeated acceleration and decelerations events between halves</p> <p>An increase in internal load (heart rate) occurred across halves within games</p>
Higham et al. (2016) (20)	International	24	International	4	<p>Differences in match demands existed between positional groups</p> <p>Backs attained higher maximal velocities, performed more accelerations and decelerations, and covered more distance above 3.5 m·s⁻¹ than forwards</p> <p>No differences were found within game in physiological profiles between positional groups</p>
Clarke et al. (2017) (10)	International and national	International: 13 National: 18	International and national	International: 1 National: 1	<p>A significant difference existed between the number of impacts in international vs national tournaments</p> <p>Total distance, relative total distance and maximum speed did not differ across playing levels</p>

Study	Standard of Player	Participants (n)	Tournament Level	Tournament (n)	Main Findings
Clarke et al. (2016) (25)	International	12	International	1	The precision and recall of quantifying collision using microtechnology devices was lower than previously reported in 15-a-side Rugby Union and Rugby League
Couderc et al. (2016) (30)	International	12	National	1	Rugby Sevens was characterized by high relative running demands and relative high-speed demands A negative relationship between blood lactate concentrations and peak activity existed within the final quarter of games Rugby Sevens players must tolerate substantial levels of acidosis during matches

For the women's game (Table 2.2), total distances covered over the course of a complete game range between 1150 to 1800 m, with relative demands between 75 to 115 m·min⁻¹. Approximately 60 to 225 m of the game is spent at high running speeds (≥ 3.5 m·s⁻¹) with an additional 80 to 200 m spent sprinting (≥ 6.0 m·s⁻¹) (2, 4, 10, 11, 23). The average distance sprinted is between 15 to 22 m and the typical maximum sprint is around 35 to 55 m. Players will achieve average top speeds ranging between 6.8 to 7.9 m·s⁻¹ (2, 4, 10, 23).

Players are typically involved in 0.2 to 0.4 tackles per minute, 3 impacts (> 8 g) per minute, and on average 1.1 to 1.5 collisions per minute; a collision is defined as a player colliding with another in either attack or defense, either in possession of the ball or immediately after its release (2, 25). In the women's game, 75 to 85% of the game is played at heart rates greater than 80% of maximum with approximately 3 min of play spent between 80 to 90% of maximum heart rate and greater than 8 min spent above 90% of maximum heart rate.

Table 2.2. Summary of studies on match demands in women’s Rugby Sevens.

Study	Standard of Player	Participants (n)	Tournament Level	Tournament (n)	Main Findings
Suarez-Arrones et al. (2012) (4)	International	12	National	1	First study to report match demands for female Rugby Sevens
Portillo et al. (2014) (2)	International and national	National: 10 International: 10	International and national	National: 1 International: 1	Greater relative demands for women’s Rugby Sevens vs. men’s 15-a-side Rugby Union Significant differences in total distance, high-speed distance, and sprint distance exist between international and national caliber tournaments
Clarke et al. (2015) (11)	International	12	International	1	Regardless of playing rank significant differences existed between halves for match activity demands Distance covered by female players using the men’s threshold for high-speed running ($> 5 \text{ m s}^{-1}$) led to an under-estimation of high-speed running demands for women’s Rugby Sevens
Vescovi and Goodale (2015) (23)	International and national	National: 25 International: 22	International and national	National: 1 International: 1	A high-speed running threshold of $> 3.5 \text{ m s}^{-1}$ was a practical threshold for women’s Rugby Sevens players Significant differences in total distance, high-speed distance, and sprint distance exist between international and national caliber tournaments
					International players demonstrated lower internal load (heart rate) response within games than national players

Study	Standard of Player	Participants (n)	Tournament Level	Tournament (n)	Main Findings
Clarke et al. (2017) (10)	International and national	International: 11 National: 22	International and national	International: 1 National: 1	No significant differences were observed in total distance or relative distance across playing levels Maximum speed and relative high-speed running demands were greater in international vs. national tournaments
Clarke et al. (2016) (25)	International	12	International	1	The precision and recall of quantifying collision using microtechnology devices was lower than previously reported in 15-a-side Rugby Union and Rugby League and the ability to recall collision accuracy was poorer in females than males

Research into both the men's and women's game of Rugby Sevens (Table 2.3) indicates that it is played at high speeds under a high internal load, relative running demands are the highest amongst the rugby football codes and the contact element is relatively similar to Rugby League. Collectively, these profiles of match demands indicate that preparation for Rugby Sevens is unique. It appears inappropriate to assume that research into other rugby football codes is applicable to Rugby Sevens. It is also unlikely that competing and training in other rugby football codes would adequately prepare players for the demands of Rugby Sevens.

Table 2.3. Comparison of match demands for men's and women's Rugby Sevens.

Variable	Men	Women	Difference (%)
Total Distance (m)	1200 to 2000	1150 to 1800	4 to 11
Relative Distance (m·min⁻¹)	85 to 120	75 to 115	4 to 13
High-Speed Distance (m)	80 to 200	60 to 225	-12.5 to 33
High-Speed Distance (% of total distance)	5 to 14	4 to 16	-14 to 25
Sprint Distance (m)	50 to 200	80 to 200	-60 to 0
Sprint Distance (% of total distance)	3 to 14	4 to 14	0 to 33
Average Top Speed (m·s⁻¹)	7.2 to 8.1	6.8 to 7.9	3 to 6
Mean Heart Rate (% max)	84 to 90	80 to 87	3 to 5
Tackle Rate (tackles·min⁻¹)	0.3 to 0.5	0.2 to 0.4	20 to 30

Data are reported as ranges. Men's high-speed running (≥ 5.0 m·s⁻¹), women's high-speed running (≥ 3.5 m·s⁻¹)

Unlike in the men's game, the majority of research into match demands for women has been conducted on either national players or international players competing in national level competitions (2, 4, 23). Only recently has a body of literature begun to emerge examining international level competition (10, 11, 25). The lack of information on the specific demands on international women's Rugby Sevens constitutes a significant gap in the body of knowledge relating to female athletes and Rugby Sevens. Research and associated performance metrics performed on international men's Rugby Sevens would be illogical to apply in an absolute fashion

to international women given the existing knowledge of differences in match demands and sex. Prescribing training interventions for females from conclusions drawn from work on males would be irresponsible of coaches and practitioners working with female players as it could result in incorrectly prescribed training interventions, suboptimal standards of play and perhaps a higher risk of injury.

2.1.2 Match Demands and Contextual Factors

The effect of a number of contextual factors including playing rank, game half, playing position, substitution, opponent rank and score line (1, 2, 10, 22-24, 27, 28) on match demands in both men's and women's Rugby Sevens has been examined. The selected contextual factors appear most frequently in the literature and are detailed in the following sections.

2.1.2.1 Competition Level

When tournaments of varying competition level have been examined, a number of differences in the demands of the game have been identified. In men's Rugby Sevens, international tournaments are characterized by significantly greater running speeds (+4 to 6%), increased distances spent running at high-speed (+ 10 to 16%) and sprint running velocities (+15 to 27%) than domestic or developmental level tournaments (1). In contrast, similar total and relative distances have been found between domestic and international levels of competitions. During international competitions players undertake a significantly greater number of moderate and high-intensity accelerations and decelerations (+12 to 22%), as well as a significantly greater number of tackles and collisions per minute of play (+12 to 16%) (1, 22).

Tactical examination (8, 13, 28, 31) of varying levels of Sevens competition have also shown that elite matches tend to be longer, have greater amounts of total time where the ball is in play, as well as longer game cycles of ball-in-play. Elite players also complete more passes, have a greater number of ball carries, complete a greater number of effective tackles and participate in more game involvements such as offensive and defensive rucks. Elite players also perform a greater number of successful attacking and defensive rucks (13). This indicates that for the men's game, not only do the physical demands differ between levels of competition but so too do the technical, tactical and decision making demands. This high level of physical, technical, tactical and decision making demand seen in the top level of Rugby Sevens places players under a high cognitive load, as well as a high external and internal physical load compared with players participating in lower level competitions.

Differences in the physiological and movement demands of different competitive levels have also been observed in the women's game (2, 10, 23). Higher level of women's competition is associated with both greater absolute and relative game demands. Players competing in higher standard competitions travel 17% significantly greater total and relative distances in games. Average speed (+10 to 15%), peak speed (+8 to 12%), number of sprints (+40 to 75%), distance sprinting ($\geq 6.0 \text{ m}\cdot\text{s}^{-1}$) (+35 to 50%) and the distance in the high-speed bands ($\geq 3.5 \text{ m}\cdot\text{s}^{-1}$) (+40 to 50%) are all significantly greater in higher level competitions (2, 10, 23).

Female players of higher rank also perform a significantly greater number of high-intensity accelerations and decelerations (+10 to 18%) and are involved in a significantly greater number of impacts ($> 10 \text{ g}$) (+15 to 23%) (2, 10). Physiological demands are also significantly greater at

higher levels, characterized by 10 to 20% greater total time above 90% maximum heart rate (2, 23). Significantly greater metabolic power demands at high (+27 to 31%), very high (+22 to 36%) and maximal (+ 34 to 57%) levels also exist between higher and lower playing levels (2, 23). Elite players displayed significantly lower mean (-5 to 10%) and maximum heart rates (-6 to 10%) than second level players, possibly indicating a higher level of energy system development in players of higher playing level, especially considering that work-to-rest ratios are significantly greater in the higher level competitions (1:0.3 vs 1:0.5) (2, 23).

Compared with the men's game, a greater disparity exists between activity and physiological profiles with respect to competition levels in the women's game. This indicates that 1) developmental competitions may be of insufficient intensity to adequately prepare developmental players for the demands of international level competition and 2) that considerations may need to be made on augmenting player development pathways in the women's game to adequately prepare development level performers for international competition.

As differences in match demands exist between playing rank, basing training prescriptions for women's programs on data from athletes of lower playing rank risks underpreparing international athletes for competition, potentially leading to underperformance and injury. In order to best prepare female players for international match-play further research into the specific game demands of international women's Rugby Sevens is required.

2.1.2.2 Game Half

When examining the changes in match demands within men's games, distance covered by both backs and forwards significantly decreases by ~8% from the first to the second half indicating a potential aerobic power/capacity gap in these players (1, 22, 27, 28). This results in an approximate 6 to 12% significant decrease in relative intensities, accompanied by a significant decrease in distances covered in high-speed running (-10 to -14%) and at sprinting speeds (-8 to -12%) (1, 24, 29). Average velocity (-2 to -5%), the number of sprints (-10 to -20%) and the number of medium (-14 to -20%) and high accelerations (-16 to -30%) also significantly decrease from the first to second half (1, 22, 24, 29). Repeated-sprint sequences (-23 to -32%) and repeated-acceleration sequences (-26 to 40%) significantly decrease from the first to second half.

Mean heart rate (+8 to 10%), maximum heart rate (+6 to 10%), time above 80% (+8 to 10%) and 90% (+10 to 30%) maximum heart rate all significantly increase from the first to second half. With decreased movement demands from the first to second half, the accompanying increase in physiological strain is most likely due to either inadequate recovery between halves or underdeveloped aerobic profiles, with only a 2-minute half time for recovery.

Although most movement profiles decrease between halves, top running speeds, impacts, tackles and rucks appear to remain consistent throughout the course of a game (1, 22). Blood lactate concentrations also significantly increase from the start ($3.9 \pm 0.9 \text{ mmol}\cdot\text{L}^{-1}$) to the finish of games ($11.2 \pm 1.4 \text{ mmol}\cdot\text{L}^{-1}$) as well as from the end of the first half ($8.7 \pm 1.7 \text{ mmol}\cdot\text{L}^{-1}$) to the second half ($11.2 \pm 1.4 \text{ mmol}\cdot\text{L}^{-1}$) indicating that the game of Sevens places a high level of stress upon an athlete's anaerobic glycolytic energy systems (27, 30). Based off 1-2 minute rolling periods of

match activity it can be seen that across the course of game halves, transient fatigue results in peaks and troughs of relative playing intensity within halves, indicating that athlete's may undertake pacing strategies in order to manage the physiological strain they experience (27-29).

Significant differences in the demands between the first and second half have also been observed in the women's game (2, 4). Total distance and distances covered in high-speed running and sprinting significantly decrease between the first and second half (-18% and -10% respectively) (2, 4). Average velocity also significantly decrease (-4 to -8%) along with the number of high-intensity accelerations and decelerations (-10 to -16%) (2). Total time above 90% of maximum heart rate significantly increases (+3 to 6%) across the course of game. As in the men's game, a two-minute half-time is insufficient for female players to completely recover from the stress of the first half before the commencement of a second half, and therefore physiological fatigue accumulates from the first to second half (2, 27).

Thus, in both men's and women's Rugby Sevens, a two-minute half time between game halves offers insufficient recovery from the high relative activity demands, internal load and metabolic stress of the first half of play. This indicates that players must be well conditioned both aerobically and anaerobically not only to prepare them for the game demands but to support their recovery during in-game breaks in activity, between halves and over multiple games in a day. However, a better understanding of the temporal patterns of match demands due to physiological mechanisms exists in men's than women's Rugby Sevens. The relationship between activity patterns and metabolic fatigue indicates that in men's Rugby Sevens, athletes need to be prepared to handle the accumulation of high levels of acidosis. Research in this area with women's Rugby Sevens has

been limited to descriptive work. In contrast with men's Rugby Sevens, there is limited understanding of both the temporal pattern of match demand and the physiological mechanisms underlying these patterns in the women's game.

2.1.2.3 Positional Groups

Playing position can affect match demands in men's Rugby Sevens. Backs have been found to cover significantly greater total distance than forwards in both the first (+12%) and second half (+13 to 20%) of games (27). Backs have also been found to cover significantly greater total relative distance (+15 to 23%), relative high-speed (+27 to 38%) and relative sprint distance (+24 to 40%) than forwards. Forwards are involved in a significantly greater number of impacts (+10 to 18%) (> 8g) and perform more tackles (+30 to 45%) than backs (22).

To date, no difference between match demands have been found between positional groups in women's Rugby Sevens (10). However, due to the emerging nature of women's Rugby Sevens further investigations into positional group differences are warranted. As women's Rugby Sevens remains in the early stages of its professionalization, it is possible that currently players are being selected primarily on general athleticism (10). The current elite female Rugby Sevens "athletes" continue to learn the specific technical and tactical skills unique to Rugby Sevens. Therefore, it is plausible that differences will begin to emerge between playing groups within the women's game just like the men's game. Continued monitoring of potential positional differences in women's Rugby Sevens is needed to track the possible evolution of the game as well as the physiological and physical characteristics of its players. It is postulated that in the coming years, distinct

differences will emerge in playing positions in women's Rugby Sevens requiring a modification in player preparation strategies across positional groupings.

2.1.2.4 Substitutions

Substitutions are typically made during the second half of games. A team has five substitutes with whom a total of five interchanges can be made across the course of the game. As in 15-a-side Rugby Union (32) and Rugby League (33) male substitutes have been found to perform at significantly higher relative playing intensities (+10 to 20%) than players who play the entire game (1, 28). Substitutes also cover significantly greater distances in the top running bands (+25 to 50%) as well as perform significantly more high-intensity accelerations and decelerations compared to players competing in full games (+ 12 to 25%) (1).

Substitutes used later in the second half also perform at significantly higher relative intensities (+10 to 15%) than substitutes who are used earlier in the second half (28); demonstrating that either fatigue, pacing, or both occurs even in substitute players. Although Rugby Sevens matches are short in duration (14 min total game length), they are played at high relative running demands ($> 90 \text{ m} \cdot \text{min}^{-1}$); substitutes can be used at key times in games where pacing is likely to occur (27). This practice strategically inserts players to take advantage of pacing decreases in relative game speed. Future research should look to characterize substitute players as well as the effect of substitutes in women's Rugby Sevens. Combined with pre-existing gaps in our knowledge with respect to pacing strategies and temporal patterns of match demands, a large gap exists in understanding the specific nature of substitute interchanges and their effect on game play in women's Rugby Sevens. As demonstrated sex differences exist between men's and women's

Rugby Sevens match demands, it is likely that differences also exist specific to substitute play between men's and women's Rugby Sevens.

2.1.2.5 Opponent Rank and Score-line

Only one study has examined the effect of opponent rank, game margin and game outcome on match demands in men's Rugby Sevens (28). In international men's Rugby Sevens both the quality of opponents and within game score can also affect the time course of match demands (28). Activity levels have been found to be influenced by contextual factors such as score and quality of opponent. Regardless of opponent rank, relative running and high-speed running demands are significantly greater (+9- to 13%) when the score line is close or when teams are winning (28). When competing against opponents of a higher rank, players cover significantly greater relative distance and relative high-speed distance (+16 to 30%) than during games against opponents of a lower rank. Therefore, opponent tactics and athlete perception of opponent skill and playing level can affect movement demands that occur within games.

To date, similar studies have not been performed in female competitors, with the majority of research being descriptive in nature. Limited investigations into changes in match activity relating to contextual factors in women's Rugby Sevens have been performed and further examination into these contextual factors are required, as understanding the match demands of games won against top opponents will support training prescription by coaching and support staff. Addressing the gaps in the current understanding of how the demands of women's Rugby Sevens are influenced by contextual factors will better inform coaches and staff of women's teams about factors that influence successful game and tournament outcomes.

2.2 Player Physical Qualities – A Comparison between Men’s and Women’s Rugby Sevens

With the rapid increase in the popularity of Rugby Sevens, researchers have characterized the physical qualities of the Sevens player (8, 12, 34, 35). As Sevens players are often selected from the game of 15-a-side Rugby Union due to the lack of a distinct Sevens pathway, this initial research has helped to identify characteristics unique to players who specialize in Sevens.

Male Sevens players have similar stature and body mass to 15-a-side Rugby Union backs (34). Male Sevens players range in stature on average from 170 to 192 cm in height and weigh on average between 75 to 102 kg (8, 15, 34, 35). Skin fold measures indicate that Sevens players are relatively lean; with sum of seven skinfold measures between 40 to 80 mm (15, 34, 36).

Male Sevens players (Table 2.4) display high levels of aerobic fitness with average relative maximal aerobic power ($\dot{V}O_{2max}$) values of 49 to 55 ml·kg⁻¹·min⁻¹ and demonstrate a velocity at $\dot{V}O_{2max}$ ($v \dot{V}O_{2max}$) of 3.9 to 4.6 m·s⁻¹ (34). Speed tests reveal that Sevens players cover 0 to 10 m in approximate 1.6 to 1.9 s, 0 to 30 m in 3.0 to 4.3 s, and 0 to 40 m in approximately 4.9 to 5.4 s. Maximum velocities of 8.6 to 9.6 m·s⁻¹ over 40 m distances have been reported (14, 34, 35). The mechanical sprint properties of Rugby Sevens players are similar to professional Rugby League and 15-a-side Rugby Union players (37) with players producing maximal power (P_{max}) outputs of 18.0 to 18.7 W·kg⁻¹, theoretical maximal forces (F_0) of 7.9 to 8.2 N·kg⁻¹, and theoretical maximal velocities (V_0) of 9.0 to 9.5 m·s⁻¹ (14). Repeated-sprint abilities have been tested using a 10 x 40 m repeated-sprint test (performed on a 30 s cycle) with international players averaging 5.2 to 5.7

s across the 10 sprints (35). The lower body power of international Sevens players are also well developed, with vertical jump heights ranging from 59-73 cm, producing 78 to 85 $\text{W}\cdot\text{kg}^{-1}$ relative peak power, and 48 to 50 $\text{W}\cdot\text{kg}^{-1}$ relative mean power outputs at jump velocities of 2.5 to 3.8 $\text{m}\cdot\text{sec}^{-1}$ (15, 35). Upper-body strength levels for the one repetition maximum (1RM) bench press of 110 to 140 kg and the 1RM pull up of 110 to 155 kg and lower-body strength levels for the 1RM squat of 140 to 160 kg have also been measured in provincial and international caliber players (15, 35). Therefore, the male Rugby Sevens player is required to be aerobically fit, display high running velocities producing high relative power and force outputs, have a powerful lower body, and display relative upper-body and lower-body strength levels of 1.0 to 1.5 and 1.5 to 1.7 times their body mass, respectively (15, 35).

Table 2.4. Summary of studies on player physical qualities in men’s Rugby Sevens.

Study	Standard of Player	Participants (n)	Physical Testing	Main Findings
Higham et al. (2013) (34)	International	18	Anthropometrics, 40 m sprint (10, 20 and 30 m splits), vertical jump, yo-yo intermittent recovery level 1, 6 x 30 m repeated-sprint ability, VO ₂ max, and vVO ₂ max	<p>First study to report physical qualities for international men’s Rugby Sevens players</p> <p>Rugby Sevens players required speed, muscle power, and aerobic and anaerobic endurance</p> <p>Significant differences existed between Rugby Sevens and 15-a-side Rugby Union players, with Rugby Sevens players being lighter, shorter, leaner, faster and more aerobically and anaerobically fit than 15-a-side Rugby Union players.</p>
Ross et al. (2014) (35)	International and national	International: 22 National: 43	Anthropometrics, 40 m sprint (5 and 10 m splits), vertical jump, 10 x 40 m repeated-sprint ability, 1 repetition maximum bench press and chin up, 20 m multistage fitness test	<p>Substantial differences were found in all anthropometric and performance tests between players of international and national playing rank. International players were larger, leaner, faster, stronger, jump higher and had greater aerobic fitness than national players</p> <p>Rugby Sevens forwards were taller and heavier than backs. Rugby Sevens backs were faster than forwards. Rugby Sevens forwards and backs shared more physical similarities than differences suggesting that similar physical qualities are needed between the different positional groups</p>
Mitchell et al. (2016) (15)	International	14	Anthropometrics, vertical jump 1 repetition maximum bench press, chin up, and squat	<p>Rugby Sevens forwards and backs had similar physique and physical qualities to professional 15-a-side Rugby Union backs.</p> <p>Across a season of Rugby Sevens upper body strength can continually be improved whereas lower body strength was more difficult to maintain, possibly due to in season training and travel demands</p> <p>Positional differences existed in the ability to maintain lower body power output across a season. Compared with backs, forwards struggled to maintain jump height and power output across a season of Rugby Sevens</p>

Study	Standard of Player	Participants (n)	Physical Testing	Main Findings
Clarke et al. (2017) (10)	International and national	International: 13 National: 18	Anthropometrics, 40 m sprint (10 and 30 m splits), vertical jump, yo-yo intermittent recovery level 1	International backs were faster and covered more distance in the yo-yo intermittent recovery level 1 test compared with national backs
Marrier et al. (2017) (14)	International	10	30 m sprint, isometric mid-thigh pull, cycle ergometer repeated-sprint test	Sprint performance, maximal strength and cycle ergometer repeated-sprint performance were sensitive to reductions in training volumes. Reducing training volumes for 1-2 weeks allowed for performance to overcome fatigue in the performance-fatigue model Sprint performance decayed at a faster rate than strength or cycle ergometer repeated-sprint performance

$\dot{V}O_2\text{max}$ = maximal aerobic power, $v \dot{V}O_2\text{max}$ = velocity at maximal aerobic power

Female Rugby Sevens players (Table 2.5) weigh between 60 to 80 kg and are on average between 160 to 175 cm tall (2, 4, 9, 10). Sum of seven skinfolds of 55 to 95 mm have been measured in international women's players (2, 4, 9, 10, 16).

Like men, female Sevens players display high levels of aerobic fitness with average relative $\dot{V}O_{2\max}$ levels of 47 to 54 ml·kg⁻¹·min⁻¹ and demonstrate a velocity at $\dot{V}O_{2\max}$ ($v \dot{V}O_{2\max}$) of 3.5 to 4.7 m·s⁻¹ (9). Speed tests reveal that women's Sevens players cover 0 to 10 m in approximate 1.7 to 1.9 s and 0 to 40 m in approximately 5.2 to 5.8 s with average maximum velocities of 7.8 to 8.6 m·s⁻¹ being reported (10, 16) Initial sprint momentum and final sprint momentums of 340 to 410 and 515 to 620 kg·m·s⁻¹ over 0 to 10 m and 30 to 40 m splits have been measured in international caliber players (10, 16). Vertical jump heights of 40 to 54 cm, producing 58 to 64 W·kg⁻¹ relative peak power and 24 to 35 W·kg⁻¹ relative mean power outputs and horizontal jump distances of 210 to 230 cm for single and 670 to 740 cm for triple long jumps have been measure in international women's Sevens players (10, 16). Upper-body strength levels for the 1RM bench press of 55 to 75 kg and the 1RM pull up of 70 to 90 kg and lower-body strength levels for the 1RM squat of 70 to 95 kg and 1RM power clean of 62 to 80 kg have been measured in international caliber players (16). Similar to male Rugby Sevens players, female Rugby Sevens players (Table 2.6) are required to be aerobically fit, display high running velocities, have a powerful lower body, and display relative upper-body and lower-body strength levels of 1.0 to 1.2 and 1.0 to 1.3 times their body mass, respectively (10, 16).

Table 2.5. Summary of studies on player physical qualities in women’s Rugby Sevens.

Study	Standard of Player	Participants (n)	Physical Testing	Main Findings
Clarke et al. (2014) (9)	International	12	VO ₂ max and vVO ₂ max	By using vVO ₂ max a sex specific high-speed running velocity threshold can be established for female Rugby Sevens players
Agar-Newman et al. (2015) (16)	International	24	Anthropometrics, 40 m sprint (10, 20 and 30m splits), horizontal jump, 1600m time trial, 1 repetition maximum bench press, chin up, power clean, and squat	Very few differences were found between international women’s Rugby Sevens backs and forwards. Forwards were found to be heavier and to generate more momentum across the first 10 m of a 40 m sprint than backs.
Clarke et al. (2017) (10)	International and national	International: 11 National: 22	Anthropometrics, 40 m sprint (10 and 30 m splits), vertical jump, yo-yo intermittent recovery level 1	International player were leaner, faster and covered more distance in the yo-yo intermittent recovery level 1 test compared with national players

VO₂max = maximal aerobic power, v VO₂max = velocity at maximal aerobic power

Few physical qualities studies have been performed on female than male Rugby Sevens players. Compared with men, the studies on women have yet to examine important physical qualities needed for Rugby sevens such as repeated-sprint ability or mechanical sprint properties. Understanding these abilities in women's Rugby Sevens players is required to 1) support the development and training of these physical qualities and 2) examine the relationship of these physical qualities to player selection, match demands, and technical-tactical variables. Creating robust physical player profiles will support coaches and support staff in making decisions around training, and supporting the development of players who are both physically prepared and resilient to the demands of Rugby Sevens.

Table 2.6. Comparison in player physical qualities between Men's and Women's Rugby Sevens players.

Variable	Men	Women	Difference (%)
Height (cm)	170 to 192	160 to 175	6 to 10
Mass (kg)	75 to 102	60 to 80	25 to 28
Sum of Seven Skinfolds (mm)	40 to 80	55 to 95	18 to 35
Maximal Aerobic Power (ml·kg⁻¹·min⁻¹)	49 to 55	47 to 54	2 to 5
Velocity at $\dot{V}O_{2\max}$ (m·s⁻¹)	3.9 to 4.6	3.5 to 4.7	2 to 12
10 m Sprint (s)	1.6 to 1.9	1.7 to 1.9	0 to 6
40 m Sprint (s)	4.9 to 5.4	5.2 to 5.8	7 to 2
Maximum Velocity (m·s⁻¹)	8.6 to 9.6	7.8 to 8.6	10 to 12
Vertical Jump Height (cm)	59 to 73	40 to 54	35 to 47
1RM Bench Press (kg)	110 to 140	55 to 75	87 to 100
1RM Pull Up (kg)	110 to 155	70 to 90	57 to 72
1RM Squat (kg)	140 to 160	70 to 95	68 to 100
Relative Upper Body Strength Ratio (kg·kg⁻¹)	1.0 to 1.5	1.0 to 1.2	0 to 25
Relative Lower Body Strength Ratio (kg·kg⁻¹)	1.5 to 1.7	1.0 to 1.3	30 to 50

Data are reported as ranges. RM = Repetition Maximum, v $\dot{V}O_{2\max}$ = velocity at maximal aerobic power

2.2.1 Player Physical Qualities – Differences between Positions and Playing Rank

Just as differences in game demands have been found between levels of competitions, differences in physical characteristics exist between players of differing rank. International male players are significantly faster over 10 m (+3 to 5%) and 40 m (+3 to 6%) distances, carry significantly more initial (+10 to 20%) and final momentum (+12 to 24%) throughout a sprint, and attain significantly higher peak velocities (+5 to 8%) than developmental male players (10, 35). International male players are also significantly stronger in the upper-body (+10 to 30%), jump higher (+9 to 21%) run further in a multi stage aerobic fitness test (+12 to 27%) and have significantly faster average repeated-sprint times (+4 to 8%) than developmental level players (10, 35). International players are also significantly older (+4 to 20%), heavier (+5 to 15%), taller (2 to 4%) and have leaner body compositions (-6 to -24%) than their developmental counterparts (10, 35).

Differences in physical qualities also exist between national and international female players. International caliber females are significantly faster over 10 m (+10 to 15%) and 40 m (+10 to 30%) distances, carry significantly more initial (+8 to 16%) and final momentum (+17 to 30%) throughout a sprint, and attain significantly higher peak velocities (+11 to 18%) than developmental female players (10). International female players also jump significantly higher (+12 to 19%) and run significantly further in a multi-stage aerobic fitness test (+80 to 100%) than developmental level players (10). International players are significantly lighter (-5 to -8%), shorter (-2 to -4%) and have leaner body compositions (-40 to -60%) than their developmental counterparts (10). The emerging status of the women's game most likely explains the stark difference in physical qualities between national and international caliber female Rugby Sevens players. Currently players are able to represent their nation by being skillful while lacking well-

developed physical properties. As the sport continues to evolve this will cease to be the norm and become the exception as players will be required to have both well-developed physical and skill qualities.

When comparing male Rugby Sevens backs and forwards, forwards have been shown to be significantly taller (+4 to 8%) and heavier (+6 to 15%). In comparison with backs, forwards also display significantly greater upper-body strength (+7 to 15%) and relative lower-body power outputs in both unloaded (+8 to 28%) and loaded (+12 to 28%) conditions (34, 35). Backs are significantly leaner (-5 to -20%) and faster over both 10 m (+4 to 6%) and 40 m (+3 to 5%) distances (34). These differences reflect the different tactical demands required of forwards and backs during a game. Forwards are involved in set piece play and tend to be involved in more restarts and rucks; all of these game movements require a tall, heavy, muscular and powerful athlete. Backs are required to perform a greater amount of attacking movements, requiring them to typically run greater distances and at higher velocities as they get into the open field of play.

Recent comparisons of the physical qualities between positional groups in international women's Rugby Sevens have found minimal significant differences (10, 16). In both studies, extensive testing batteries were conducted examining a number of physical qualities: anthropometry, speed, momentum, lower body power output, aerobic fitness, and upper-body and lower-body strength. International female forwards were significantly taller (+3 to 6%) and heavier (+8 to 12%). Forwards carried significantly more initial (+9 to 15%) and final momentum (+10 to 18%) throughout a sprint than backs. Backs were significantly faster over 10 m (+3 to 5%) and 40 m (3 to 6%) sprint distances compared to forwards. Both of these studies indicate that fewer differences

in positional physical qualities exist in women's Rugby Sevens than in men's Rugby Sevens . Compared with the men's game, the women's game remains in relative infancy; the lack of physical differences in positional groups early in the sports professionalization may indicate that the tactical demands of positional groups are not yet highly specialized.

In comparison with male 15-a-side Rugby Union players, Rugby Sevens players are significantly leaner, with 15-61% lower total skinfold measures (36). Male Sevens players are also significantly faster over 40 m (2 to 8%) and have a significantly better-developed high-intensity running ability (36% greater total distance on Yo-yo intermittent recovery level 1 (Yo-Yo IR1)) (34, 36). $\dot{V}O_{2\max}$ values have been shown to be comparable but repeated-sprint ability is significantly greater in the Sevens athlete (34, 36).

The distinctive anthropometric and fitness characteristics are similar to the differences seen in the movement demands during competitive games between men's Sevens and 15-a-side Union. Specifically, men's sevens' games result in 45% significantly greater relative distance demands and over 135% significantly greater relative high-speed running demands ($\geq 5.0 \text{ m}\cdot\text{s}^{-1}$) than 15-a-side Rugby Union (13).

In addition, on average men's Sevens players tend to be significantly younger (2 to 3 years) than Union players. This could be a result of Sevens being used by most countries to develop players for their professional and national Union teams. This trend may change over time as: 1) the popularity of Rugby Sevens increases; 2) the initiation and development of Rugby Sevens player

pathways begins; and 3) the allure of Olympic Game participation results in players specializing younger in Sevens but also remaining in the game rather than departing for opportunities in other rugby codes such as Union and League.

2.3 Player Physical Qualities and Match Performance

Unlike in male Rugby League (26, 38, 39) or male Australian Rules football (40), very limited research has been conducted on the relationship between player physical qualities and match demands or performance in male Rugby Sevens. To date, only one study has examined the relationship between player physical qualities and tactical match performance (8). Attacking tactical outcomes such as defenders beaten, handling errors, line breaks, and scoring effectiveness were related to the physical qualities of speed, repeat-sprint ability and lower body power (8). Defensive tactical outcomes such as tackle score, dominant tackles, defensive rucks, and tackle completion were related to repeated-sprint ability, upper-body strength and lower-body power (8). Match performance variables associated with winning performances in men's Rugby Sevens included maintaining ball possession, avoiding contact, limiting turnovers, limiting passing and high rates of tackle completion (31). Therefore, male Rugby Sevens players need to be fast in both one-off and repeated situations, have strong upper bodies and maintain powerful lower bodies to more effectively execute the tactics required for successful game outcomes.

To date, no studies have been conducted on either sex exploring the relationship between player physical qualities and match demands. This gap in knowledge currently limits the ability to specifically assess and prepare players for performance in Rugby Sevens. Understanding the relationship between physical qualities and match demands will assist the preparation of players

throughout the Rugby Sevens development pathway. Knowing which player physical qualities support game demands and in game moments will not only better inform training prescription but will also help to identify the physical characteristics that might contribute to success in Rugby Sevens. This knowledge can benefit players of all rank and also help identify talent.

2.4 Conclusions and Recommendations

To date, the research on Rugby Sevens demonstrates that it is a unique game from the other football codes. It is a game characterized by both extreme movement and physiological demands and is played by dynamic and fit players. The game and the competition structure of Sevens results in a unique sport that has recently increased in popularity due to its inclusion in the Olympic Games. As it is still an emerging sport on the world stage compared with the other football codes there is a paucity of research on Rugby Sevens.

Furthermore, not only are there very few studies investigating the women's game, a number of studies into sex based differences in athletes have demonstrated that male and female sports have inherent physiological and movement differences. This results in gaps in understanding the subtle and strategic differences in male and female team sport competition.

To understand the game and promote maximal development, a number of questions around the sport remain unanswered. An urgent opportunity exists for a series of studies examining the foundational and practical aspects of the women's game. Areas of research that warrant investigation with respect to the women's game include: 1) the physical qualities that differentiate

developmental from elite performers; 2) the movement and physiological demands of top level international level competitions; and 3) and the relationships between physical characteristics and game demands.

With this in mind, this thesis aims to:

- (1) describe the physical qualities differentiating playing selection at the international level of competition (Study 1);
- (2) examine the relationship between match activity and physiological profiles and contextual factors such as game outcome, half, margin, and opponent rank for international women's Rugby Sevens (Study 2);
- (3) describe the difference in match activity demands and tactical phase of play and how these differences relate to game outcome (Study 3);
- (4) study the relationship between player physical qualities, match activity and physiological profiles and contextual factors (Study 4).

By conducting these studies, the thesis aim to address the numerous gaps identified within the body of knowledge relating to international women's Rugby Sevens. By addressing these specific questions, the results will provide information to coaches, strength and conditioning coaches and sport scientists working in international women's Rugby Sevens on how to successfully prepare female players for the requirements of the elite game. Ultimately dissemination of the results of this thesis will also add to the foundational knowledge of not only women's Rugby Sevens but women's team sport in general.

Chapter 3: Relationship between Physical Qualities and Minutes Played in International Women's Rugby Sevens

This study has been accepted for publication following peer review. Full reference details are:

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3.1 Abstract

We investigated the physical qualities that differentiated playing minutes in international-level women's Rugby Sevens players. Twenty-four national-level female Rugby Sevens players underwent measurements of anthropometry, acceleration, speed, lower- and upper-body strength, lower-body power and aerobic fitness. Playing minutes in international competition were used to differentiate players into two groups; a high and low playing minute group. Playing minutes were related to team selection which was determined by the coaching staff. Playing minutes were therefore used to differentiate performance levels. Players in the high playing minute group (≥ 70 min) were older (mean \pm SD: 24.3 \pm 3.1 vs. 21.2 \pm 4.3 years, $p=0.05$, Effect Size (ES)=0.77 \pm 0.66, 90% Confidence Limit), had greater experience in a national training centre environment (2.4 \pm 0.8 vs. 1.7 \pm 0.9 years, $p=0.03$, ES=0.83 \pm 0.65), faster 1600-m time (374.5 \pm 20.4 vs. 393.5 \pm 29.8 s, $p=0.09$, ES=-0.70 \pm 0.68), and greater 1RM upper-body strength (bench press 68.4 \pm 6.3 vs. 62.2 \pm 8.1 kg, $p=0.07$, ES=0.80 \pm 0.70 and neutral-grip pull-up 84.0 \pm 8.2 vs. 79.1 \pm 5.4 kg, $p=0.12$, ES=0.68 \pm 0.72) than athletes who played fewer minutes. Age ($r_s=0.59\pm\sim 0.28$), training experience ($r_s=0.57\pm\sim 0.29$) bench press ($r=0.44\pm\sim 0.36$) and 1600-m time ($r=-0.43\pm\sim 0.34$) were significantly associated with playing minutes. Neutral-grip pull-up and bench press contributed significantly to a discriminant analysis. The average squared canonical correlation was 0.46. The discriminant analysis predicted 7 of 9 and 6 of 10 high and low playing minute athletes, respectively. Age, training experience, upper-body strength, and aerobic fitness differentiated athlete playing minutes in international women's Rugby Sevens.

3.2 Introduction

Rugby Sevens is growing in popularity, with its recent inclusion in the 2016 Olympic Games. Rugby Sevens is a variation of 15-player Rugby Union, with the main difference being seven-minute halves separated by a two minute half-time in Rugby Sevens versus an 80 min game in Rugby Union. The game is normally played tournament style with two to three games per day over two to three days.

Rugby Sevens is characterized by high physical demands relative to minutes of play (1, 2, 4). Running velocities, distances covered, number of accelerations, and work-to-rest ratios are greater than in other forms of Rugby (Union and League) (6, 7). These findings suggest that training and physical preparation should be specific to the Rugby Sevens athlete. Most international programs consist of Rugby Sevens specialist players and this trend will continue as the game further evolves.

While the demands of Rugby Sevens have been documented (2, 4, 36) limited data exist on the physical characteristics of Rugby Sevens players (8, 34-36). Unlike the large body of work performed in other field sports, (39, 41-43) only one study has investigated the differences between Rugby Sevens players of different playing standards (35), and none have involved international-level female players.

In Rugby League (26, 38, 43) age, stature, mass, lean mass ratio, speed, change of direction speed, high-intensity running ability, lower-body power, and aerobic fitness are related to a player's on-

field performance and discriminate performers of varying playing levels (26, 38, 43, 44). In addition, sprinting momentum, absolute upper-body strength and strength-endurance qualities differentiated player rank (42, 45). In Australian Rules football age, speed, lower-body power, repeated-sprint ability and high-intensity running ability differentiate starters from non-starters (41, 46). While these studies provide important information on the relationship between physical qualities, performance, playing rank and team selection in contact field sport, to date no research has identified the relationships between physical qualities and team selection in female Rugby Sevens players.

Of the research that has been performed on international women's Rugby Sevens (4, 11, 47), no study has characterized the physical capacities of international-level female Rugby Sevens players in relation to playing minutes. Therefore, the purpose of this study is to examine which, if any, physical qualities differentiate playing minutes in international women's Rugby Sevens players.

3.3 Methods

3.3.1 Experimental Design

A cross sectional design was used to assess physical characteristics and their relationship to playing minutes in international women's Rugby Sevens players. Players were tested for anthropometry, acceleration, speed, lower- and upper-body strength, lower-body power and aerobic fitness over a three-day period on three to four occasions during the general preparatory (6 months) and competitive phases (5 months) of the 2013-2014 World Rugby Women's Sevens Series training cycle. Players performed the physical assessments as part of their inclusion in the

national training centre (NTC) program. Testing was performed based on the annual international competition demands. Unless a medical contraindication existed, athletes completed all tests on each testing occasion. The average scores for each test by each player during the year were used for analysis. Testing was performed in the same order and on the same days of the week following a complete day of rest. Tests were selected that would provide a comprehensive physical assessment of athlete capabilities in relation to Rugby Sevens performance. Playing minutes in international competition over the course of the 2013-2014 World Rugby Women's Sevens Series were used to differentiate players as a measure of team selection. Playing minutes were obtained via video and notational analysis. Athletes were divided into two groups using a median split; a high and a low playing minute group. Playing selection was used as a representation of performance level as top performers (as judged by the coaching staff) would be selected to play over lower performers. Selection for international competition was conducted by the coaching staff and was based on their own criteria of an international-level Rugby Sevens performer. All athletes in the NTC were available for selection to each tournament. After selection, two athletes did suffer injuries affecting their playing minutes in subsequent tournaments but not their inclusion in the high playing minute group. Athletes in the lower playing minute group who might not have played as many minutes originally may therefore have played greater minutes.

3.3.2 Participants

Twenty-four national-level female Rugby Sevens players (mean \pm SD, age 22.8 \pm 4.0 years, height 168.2 \pm 5.6 cm, mass 69.4 \pm 5.2 kg, years in NTC 2.0 \pm 0.9 years) participated in this study. Players were training full-time in a NTC program. All NTC athletes were eligible for national team selection. The national team competes on the World Rugby Women's Sevens Series as a core team

across an annual series of international competitions. All players received a clear explanation of the study and written consent was obtained. Ethical approval was obtained from the Australian Catholic University Human Ethics Research Committee.

3.3.3 Anthropometry

Skinfold thickness at seven sites (triceps, biceps, subscapular, iliac crest, abdomen, thigh and calf) was measured using a Harpenden skinfold caliper (British Indicators Ltd, UK). All tests were conducted by the same experienced *International Society for the Advancement of Kinanthropometry* anthropometrist (intraclass correlation coefficient [ICC], $r=0.99$). Height was measured to the nearest 0.5 cm using a stadiometer (Tanita, Japan) and body mass was measured to 0.01 kg using a calibrated digital scale (Avery Berkel, UK).

3.3.4 Speed

The running speed of players was assessed using a 40 m sprint effort with splits obtained at the 10, 30 and 40 m mark using wireless electronic timing gates (Brower Timing Systems, USA). Athletes started from a two-point stance 0.75 m back from the start line and were instructed to run as quickly as possible until past the final gate. Athletes were given three attempts to produce their best effort with five minutes rest given between attempts. All sprints were conducted on artificial turf (Field Turf, USA) in cleats. The fastest 40 m value and its corresponding 10 and 30 m split were recorded to the nearest 0.01 s. Average velocities were then calculated for the 0-10 m split and the 30-40 m split and then multiplied by the athlete's mass in order to calculate initial sprint momentum (ISM) and maximal sprint momentum (MSM). Speed testing data were collected on

23 of 24 players. The ICC for 10 m, 30 m, 40 m, ISM and MSM are $r=0.90$, $r=0.95$, $r=0.96$, $r=0.96$ and $r=0.97$, respectively.

3.3.5 Lower-Body Muscular Power

Lower-body muscular power was estimated using a standing long jump (SLJ) and a standing triple-long jump (STJ) for maximum horizontal distance(48). Athletes started flat-footed behind the start line straddling a measuring tape laid out and affixed to the ground on artificial field turf. Athletes were allowed a countermovement and 3 attempts were given per jump with 5 minutes rest between attempts. The furthest distance jumped from the start line to the back of the heel on the foot closest to the start line was recorded. Athletes were instructed to jump as far as possible and a visual target just beyond their personal best score was used to help elicit maximum effort. For the STJ, athletes were instructed to maintain continuity between all three jumps while landing each jump on both feet. SLJ and STJ testing data was collected on 23 of 24 four players. The ICC for SLJ and STJ are $r=0.93$ and $r=0.96$, respectively.

3.3.6 Strength

Maximal strength was assessed using one repetition maximum (1RM) testing. The power clean, front squat, bench press and neutral-grip pull-up were tested using free weights (Eleiko Sport, Sweden). Athletes performed a standardized warm up before each lift that increased in intensity while decreasing in volume or repetitions lifted. Athletes were given three attempts per lift to achieve their best performance. The heaviest load lifted was recorded. For the pull-up test the athlete's body mass and any additional load lifted (affixed to the athlete via a belt around the mid-

section) was recorded. A successful pull-up was completed when the athlete was able to pull their chin above the pull-up handles from starting with arms fully extended. For a successful lift to be recorded in the power clean the bar had to be caught with the thighs above parallel to the floor and the lift completed by extending to a full standing height. In the front squat a successful lift was recorded only if the athlete's thighs were seen by visual inspection to have been parallel with the floor; verbal acknowledgement of successful squat depth was given. In the bench press the bar could not bounce off the athlete's sternum and the athlete had to come to a fully extended arms position under their own effort. Power clean, front squat, bench press and neutral-grip pull-up strength data were collected on 15, 17, 22 and 21 players, respectively. Testing results were reported in absolute terms and relative to body mass. The ICC for 1RM strength testing was $\geq r=0.98$ (49).

3.3.7 Aerobic Fitness

Aerobic fitness was estimated using a 1600 m time-trial. The time-trial was conducted around a 400 m track in running shoes. After a standardized progressive warm up, athletes ran 1600 m (4 x 400 m) as quickly as possible. The total time was recorded to the nearest 0.01 second using a hand-held stopwatch. It was assumed that the athlete gave full maximal effort and due to the length of the test, held a speed that was representative of their aerobic fitness. Aerobic fitness data were collected on 23 of 24 players. The test-retest reliability of time-trial testing has previously been reported with an ICC of $r=0.88$ (50).

3.3.8 Statistical Analysis

Differences in physical qualities between high and low playing minute groups were compared using null hypothesis testing and by using a practical approach based on the real world relevance of the results (51). All data were tested for normality using a Shapiro-Wilk test. Differences between playing groups were evaluated using independent t-tests (normal data) or a Mann Whitney Wilcoxon test (non-normal data). All data are reported as mean \pm SD. Pearson product moment (r , normal data) or Spearman's rank (r_s , non-normal data) correlations were used to assess the relationship between the tests of physical qualities and playing minutes. Correlations of 0.0-0.1, 0.1-0.3, 0.3-0.5, 0.5-0.7, 0.7-0.9, 0.9-0.99 and 1.0 were considered trivial, small, moderate, large, very large, near perfect and perfect, respectively (51). Differences between playing groups were also analyzed using Cohen's effect size statistic. Effect sizes (ES) of <0.2, 0.2-0.6, 0.6-1.2, 1.2-2.0 and >2.0 were considered trivial, small, moderate, large and very large, respectively (51). A custom Excel work sheet (Version 14, Microsoft, USA) was used to calculate effect sizes and confidence intervals (52). A level of confidence of 90% was used for both correlations and effect-sizes. A difference between groups was deemed unclear if the confidence limit for the effect crossed the threshold for both substantially positive (≥ 0.20) and negative effects (≤ -0.20). Variables that were found to be significantly ($p \leq 0.05$) related to playing group via null hypothesis testing and/or where substantial effects (\geq moderate) were found in magnitude based inference testing were included into a linear discriminant analysis. The linear discriminant analysis was conducted to determine which, if any, physical qualities contributed to high or low minute group classification. The linear discriminant analysis provided a regression equation that could be used to predict playing group (high vs low minutes) inclusion for 5 World Rugby Women's Sevens Series events. The leave one out method of cross-validation was used to identify misclassified

observations and guard against type III errors by partitioning the data into two subsets, analyzing one subset and validating the analysis on the other subset. Variability is reduced by multiple rounds of cross-validation being performed with the results averaged over the rounds.

3.4 Results

Players were separated into high (≥ 70 min) or low (< 70 min) playing minute groups depending on their total minutes played for their national team during the five tournaments. The high minute playing group averaged 232.6 ± 124.3 minutes of playing time (6 backs and 6 forwards, across 24 games) compared to the low minute playing group (7 backs and 5 forwards, across 24 games) who averaged 23.0 ± 20.9 minutes of play. Of the 24 NTC players, 20 were selected across the World Rugby Women's Sevens series to represent their national team on at least one occasion; all 24 players had previous experience in 15-player Rugby Union. A core group of 8 players were selected to a majority of the five tournaments.

The general descriptive, anthropometric and physical qualities for both playing minute groups are shown in Table 3.1. Athletes with greater playing minutes were moderately older ($p = 0.05$, $ES = 0.77 \pm 0.66$) and had moderately more years of experience in a NTC program ($p = 0.03$, $ES = 0.83 \pm 0.65$). Athletes with higher playing minutes scored moderately better on the 1600m time-trial ($p = 0.09$, $ES = -0.70 \pm 0.68$), 1 RM bench press ($p = 0.07$, $ES = 0.80 \pm 0.70$) and neutral-grip pull-up ($p = 0.12$, $ES = 0.68 \pm 0.72$) than athletes who played fewer minutes.

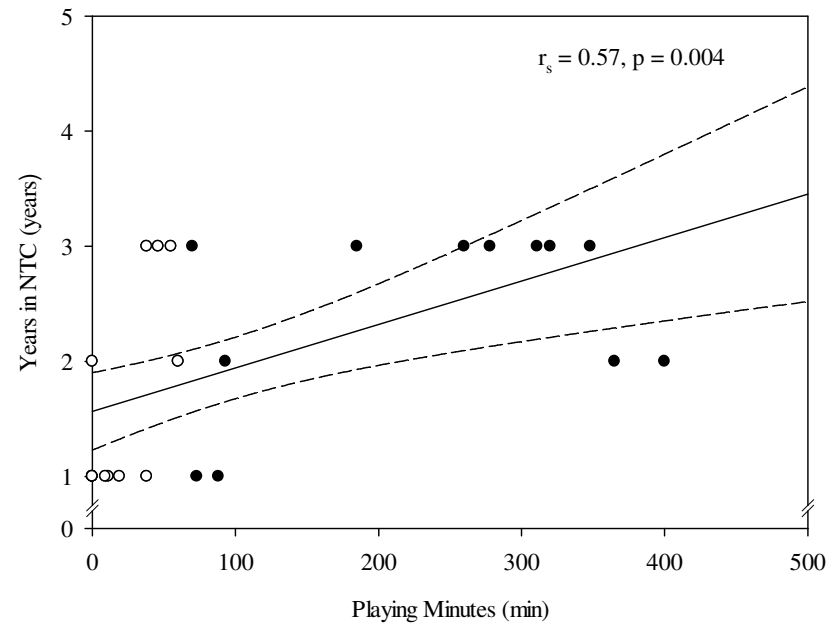
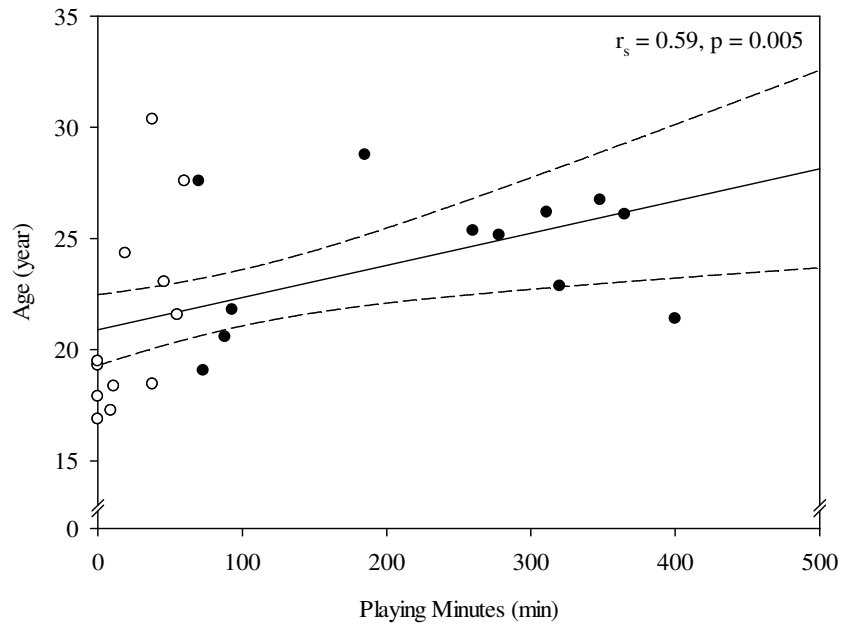
Table 3.1. Descriptive and comparative statistics for anthropometric, running speed, strength and lower-body power data for national-level female Rugby Sevens players.

Variable	High Playing Minutes (n=12)		Low Playing Minutes (n=12)		
	Mean (\pm SD)	Mean (\pm SD)	Percentage Difference (\pm CL)	Effect Size (\pm CL)	Qualitative Outcome
Age (years) *	24.3 \pm 3.1	21.2 \pm 4.3	13.6 \pm 12.2%	0.77 \pm 0.66	Moderate +ve
Years in NTC (years) *	2.4 \pm 0.8	1.7 \pm 0.9	34.6 \pm 38.3%	0.83 \pm 0.65	Moderate +ve
Height (cm)	167.7 \pm 6.7	168.8 \pm 4.5	-0.7 \pm 2.4%	-0.20 \pm 0.72	Unclear
Body Mass (kg)	70.0 \pm 4.9	68.7 \pm 5.7	1.9 \pm 5.4%	0.25 \pm 0.71	Unclear
Sum of 7 Skinfolds (mm)	86.8 \pm 11.2	91.6 \pm 28.4	-2.2 \pm 17.6%	-0.23 \pm 0.73	Unclear
Mass Skinfold Ratio (kg \cdot mm $^{-1}$)	0.9 \pm 0.1	0.8 \pm 0.2	4.1 \pm 14.2%	0.15 \pm 0.72	Unclear
10m Time (s)	1.83 \pm 0.05	1.82 \pm 0.03	0.7 \pm 1.6%	0.34 \pm 0.71	Unclear
30m Time (s)	4.41 \pm 0.13	4.39 \pm 0.07	0.5 \pm 1.8%	0.20 \pm 0.72	Unclear
40m Time (s)	5.66 \pm 0.16	5.66 \pm 0.11	0.0 \pm 1.8%	0.01 \pm 0.73	Unclear
30-40m Time (s)	1.23 \pm 0.04	1.24 \pm 0.04	-1.0 \pm 2.4%	-0.29 \pm 0.72	Unclear
IS Momentum (kg \cdot m \cdot s $^{-1}$)	386.4 \pm 20.1	377.9 \pm 32.3	2.4 \pm 5.3%	0.32 \pm 0.75	Unclear
MS Momentum (kg \cdot m \cdot s $^{-1}$)	577.0 \pm 29.1	554.9 \pm 47.1	4.0 \pm 5.1%	0.56 \pm 0.73	Small +ve
1600-m Time-Trial (s)	374.5 \pm 20.4	393.5 \pm 29.8	-5.3 \pm 4.6%	-0.70 \pm 0.68	Moderate -ve
1RM Power Clean (kg)	71.8 \pm 4.8	69.4 \pm 7.2	3.6 \pm 8.7%	0.41 \pm 0.98	Unclear
1RM Front Squat (kg)	84.2 \pm 7.9	83.0 \pm 9.6	1.6 \pm 9.6%	0.13 \pm 0.87	Unclear
1RM Bench Press (kg)	68.4 \pm 6.3	62.2 \pm 8.1	9.5 \pm 8.8%	0.80 \pm 0.70	Moderate +ve
1RM Neutral-Grip Pull-Up (kg)	84.0 \pm 8.2	79.1 \pm 5.4	5.7 \pm 6.8%	0.68 \pm 0.72	Moderate +ve
Relative Power Clean (kg \cdot kg $^{-1}$)	1.0 \pm 0.1	1.0 \pm 0.1	-2.9 \pm 7.1%	-0.41 \pm 0.97	Unclear
Relative Front Squat (kg \cdot kg $^{-1}$)	1.2 \pm 0.2	1.2 \pm 0.2	-2.2 \pm 11.4%	-0.17 \pm 0.88	Unclear
Relative Bench Press (kg \cdot kg $^{-1}$)	1.0 \pm 0.1	0.9 \pm 0.1	6.5 \pm 9.3%	0.58 \pm 0.75	Small +ve
Relative Neutral-Grip Pull-Up (kg \cdot kg $^{-1}$)	1.2 \pm 0.1	1.2 \pm 0.1	2.4 \pm 6.8%	0.30 \pm 0.76	Unclear
Standing Long Jump (cm)	227.3 \pm 9.0	230.4 \pm 11.0	-1.3 \pm 3.2%	-0.30 \pm 0.74	Unclear
Standing Triple Jump (cm)	691.9 \pm 24.9	704.8 \pm 35.3	-1.8 \pm 3.2%	-0.43 \pm 0.74	Unclear

NTC = National Training Centre, IS = Initial Speed, MS = Maximal Speed, RM = Repetition Maximum, CL = 90% Confidence Limits

*Significant difference at $p \leq 0.05$

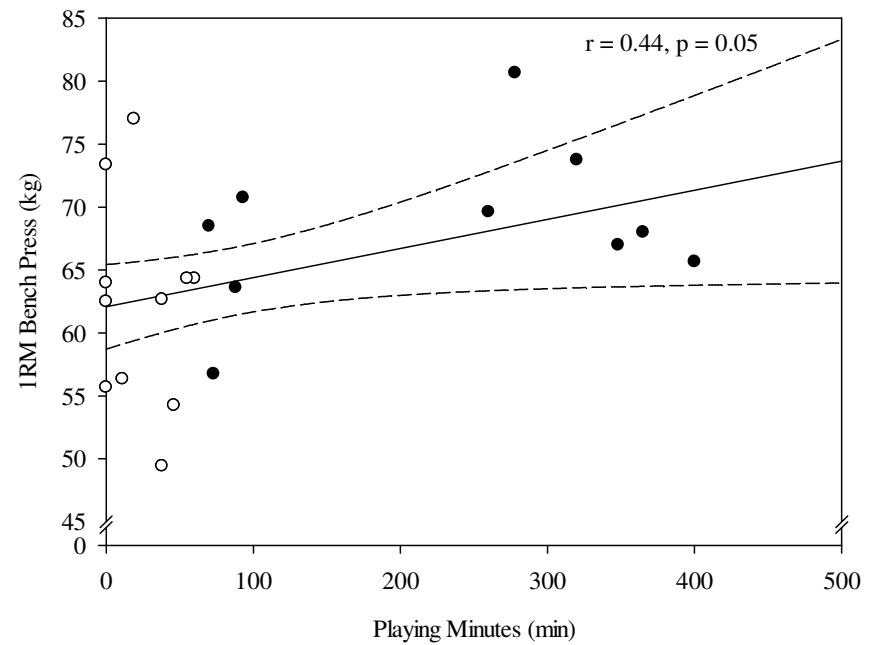
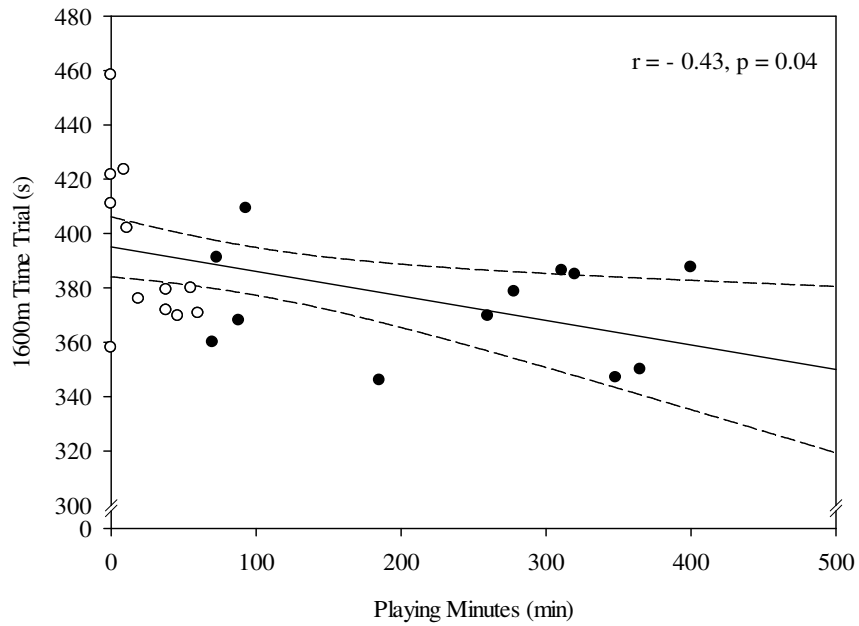
Relationships between descriptive and selected physical and anthropometric data and playing minutes are shown in Figures 3.1 and 3.2. Large associations were found between playing minutes and age and years in the NTC (age: $p = 0.005$, $r_s = 0.59 \pm 0.28$, NTC: $p = 0.004$, $r_s = 0.57 \pm 0.29$) while moderate associations were found between playing minutes and 1RM bench press and 1600m time-trial (1RM: $p = 0.05$, $r = 0.44 \pm 0.36$, 1600m: $p = 0.04$, $r = -0.43 \pm 0.34$). No other measures correlated substantially with playing minutes.



● High Playing Minute ○ Low Playing Minute --- 90% Confidence Interval

Figure 3.1. Relationships between playing minutes from five international tournaments and training experience and age for national-level female Rugby Sevens players.

NTC= National Training Centre



● High Playing Minute ○ Low Playing Minute --- 90% Confidence Interval

Figure 3.2. Relationships between playing minutes from five international tournaments and aerobic fitness and 1RM bench press for national-level female Rugby Sevens players.

RM= Repetition Maximum

Five athletes were excluded from the linear discriminant analysis due to missing data. The average squared canonical correlation of 0.464 showed that five variables accounted for 46.4% of the overall variance in the data set. The discriminant analysis correctly predicted 77.8% (7 of 9) of high playing minute athletes, and 60.0% (6 of 10) of low playing minute athletes, with an overall accuracy of 68.4% (13 of 19) for all athletes (discriminant analysis equation = $(0.133 \times \text{age}) + (0.247 \times \text{years in the NTC}) + (0.039 \times \text{1600m time-trial}) + (-0.142 \times \text{1RM bench press}) - (0.071 \times \text{1RM neutral-grip pull-up}) - 3.397$) ($p = 0.10$). The cross-validation method compensated for a 15.8% error rate.

3.5 Discussion

This study investigated the descriptive, physical and anthropometric qualities of female Rugby Sevens players and determined if any of these characteristics differentiated playing minutes at international competitions. These results demonstrate that athletes who played the most minutes of international competition were: older, had more NTC experience, had greater upper-body strength, and had better developed aerobic fitness. These findings should help prioritize training approaches and selection metrics for international-level women's Rugby Sevens.

Age and experience have previously been shown to predict playing success in male Rugby League and Australian Rules football players (26, 39, 41, 43, 46), which was supported by our data in females. These findings lend further support to both playing and training experience aiding in the development of sport expertise, as well as the coach's familiarity with the technical and tactical abilities of the players. As women's Rugby Sevens can still be classified as an emerging sport,

many countries lack direct player development pathways from grassroots through to international levels. Accordingly, international women's Rugby Sevens athletes generally come from 15-player Rugby Union, touch football or from other talent transfer programs. The relationship between playing minutes and time in a professional training environment indicates the importance of sport-specific training to enhance an athlete's ability to play Rugby Sevens at the highest level of competition.

We found that aerobic fitness was related to total playing time at international competition, which is not surprising given the repeated high-intensity intermittent nature of the sport with multiple games per day. In men's high-intensity intermittent team sports a well-developed aerobic system aids recovery between repeated high-intensity bouts, as well as facilitates recovery between multiple matches over a two-day tournament (8, 53). In women's Rugby Sevens, athletes cover over ~1120-1650m (~80-120m·min⁻¹) in a fourteen minute game with ~10-13.5% of that distance being high-intensity in nature ($\geq 5.0\text{m}\cdot\text{s}^{-1}$) (2, 4). Heart rates (HR) are maintained above 80% of maximum for over 75% of the game, with average heart rate for a game being ~89% of maximum HR and work-to-rest ratios of ~2:1 (2, 4). The running and contact demands of Rugby Sevens necessitate the need for a well-developed aerobic system to aid with recovery, although the high frequency of physical collisions also requires well-developed muscular strength and power (41, 43).

Absolute upper-body strength in both the bench press and pull-up was also found to differentiate athlete playing minutes. In Rugby Sevens, players are required to perform large numbers of

collisions and tackles; in the men's game forwards perform ~0.5 and backs ~0.3 tackles per minute of play (22). A number of other movements (e.g. rucks, line outs, scrums, fending, and the up and down off the ground nature of play) occur during the course of the game that require well-developed upper-body strength. Higher absolute strength, rather than relative strength, increases the likelihood of a player dominating a contact situation (26). The greater absolute strength of the high playing minute group was coupled with a slightly higher body mass, which resulted in no differences in relative strength between groups. The game of Rugby Sevens relies on the "absolute" physical qualities (i.e. speed, strength and power) of players. Thus, improving absolute upper-body strength may assist athletes to successfully perform these game demands, which is supported by previous research demonstrating the importance of upper-body strength to both team selection (54) and tackling ability (44). The collision demands of Rugby Sevens makes strength a requisite quality for athletes such that they can effectively tolerate the repetitive forces and trauma that occur in tackles, collisions and the physical stress associated with wrestling during match-play.

The discriminant analysis predicted seven of nine and six of ten athletes that played the most minutes and least minutes, respectively, and corresponded to an overall accuracy of thirteen out of nineteen selected athletes. This demonstrates that discriminant classification analysis predicts with slightly better than chance accuracy, athlete playing time across a series of international competitions. While a wide range of physical and anthropometric qualities were included in this study, it is possible that some unmeasured physical qualities, such as agility and repeated-effort ability may contribute to team selection. This study focused solely on physical and anthropometric qualities of national and international female Rugby Seven's athletes and did not assess technical,

tactical or mental abilities. It is therefore likely that key non-physical attributes, assessed by the head coach, contribute to playing minutes (39).

Given the high playing standard of the national training group and that talent identification is based on both tactical and physical abilities, the current sample size is relatively small and contributes to homogeneity of physical attributes such as stature, mass, speed, momentum, lower-body muscular power and lower body strength. While this is inherent in all high performance sports due to the nature of the athletic population, this may be considered a limitation of the present study. The technical and tactical nature of Rugby Sevens combined with its recent emergence as an Olympic sport has also resulted in a mixture of athletes playing the game at the international level as a leveling effect is still occurring with respect to on-field experience and raw physical talent. Due to the small sample size, the large confidence intervals in qualities such as speed, lower-body muscular power and strength resulted in effect sizes being interpreted as unclear.

3.6 Conclusions

Age, training experience, upper-body strength and aerobic fitness differentiated athletes who played high and low minutes in international women's Rugby Sevens competition. These results highlight physique and fitness qualities that are important to develop in order to aid players in competing in international women's Rugby Sevens. The athletes assessed in this study were of a homogenous nature; all were female Rugby Sevens performers selected from across the country to train in a single NTC program; thus it is possible that athletes with greater playing minutes were selected based primarily on qualities not examined in this study (e.g. technical, tactical or mental

skills). As Rugby Sevens is an emerging sport, lack of player depth can mean that those who are not physically dominant, but have superior skill, can still perform at a high level, and it is possible that there could be a levelling effect over time, where top performers will not only need to be highly skilled and tactically proficient but physically dominant as well.

3.7 Practical applications

As playing time for international-level female Rugby Sevens players can be differentiated by physical characteristics such as upper-body strength and aerobic fitness it is suggested that practitioners focus on the development of these physical attributes when preparing players for international competition. Furthermore, it would be beneficial for players to gain experience in a professional training structure as this exposure is associated with playing minutes at top tier international female Rugby Sevens competition. Talent identification and transfer programs should also measure upper-body strength and aerobic fitness when assessing athletes for the sport of women's Rugby Sevens.

Chapter 4: The Effect of Contextual Factors on Physiological and Activity Profiles in International Women's Rugby Sevens

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4.1 Abstract

We evaluated the effects of contextual game factors on activity and physiological profiles of international-level women's Rugby Sevens players. Twenty international-level female Rugby Sevens players from the same national team participated in this study. Global positioning system and heart rate data were collected at five World Rugby Women's Sevens Series events (2013-2014 season). Total running distance, moderate-speed ($0.2\text{-}3.5\text{ m}\cdot\text{s}^{-1}$) and high-speed running ($3.5\text{-}5.0\text{ m}\cdot\text{s}^{-1}$) distances were significantly greater in the first half ($20.1\pm 4.1\%$, $17.6\pm 6.9\%$, $24.5\pm 7.8\%$), during losses ($11.4\pm 6.1\%$, $6.1\pm 6.4\%$, $26.9\pm 9.8\%$), losses of large magnitudes (≥ 2 tries) ($12.9\pm 8.8\%$, $6.8\pm 10.0\%$, $31.2\pm 14.9\%$), and against Top 4 opponents ($12.6\pm 8.7\%$, $11.3\pm 8.5\%$, $15.5\pm 13.9\%$). In addition, total distance increased ($5.0\pm 5.5\%$) significantly from day one to day two of tournaments and very high-speed ($5.0\text{-}6.5\text{ m}\cdot\text{s}^{-1}$) running distance increased significantly ($26.0\pm 14.2\%$) during losses. Time spent between 90-100% of maximum heart rate ($16.4\pm 14.5\%$) and Player LoadTM ($19.0\pm 5.1\%$) were significantly greater in the second half. No significant differences in physiological or activity profiles were observed between forwards and backs. Game half, game outcome, tournament day, opponent rank and margin of outcome all affected activity profiles while game half affected physiological profiles. No differences in activity or physiological profiles were found between playing positions. Practitioners are advised to develop high-speed running ability in women's Rugby Sevens players in order to prepare players to tolerate the varying factors that impact activity profiles.

4.2 Introduction

With its recent inclusion in the 2016 Olympic Games, Rugby Sevens is rapidly growing in popularity. It is a high-intensity, intermittent collision sport (13, 29) and is a variation of 15-players Rugby Union. Both the laws and field size of the two games are similar but there are fewer players per side in the game of Rugby Sevens and games are shorter (14 minutes vs. 80 minutes) in duration. Rugby Sevens is played in a tournament structure with 2-3 games played per day over 2-3 days.

Recent research (1-4) has examined both the activity and physiological profiles of Rugby Sevens for both male and female players with the majority of this research examining the men's game (1-4, 20, 22, 24) Rugby Sevens has higher physical demands relative to minutes of play than in other forms of Rugby (Union and League) with relative distances of 85-120 m·min⁻¹ covered, and work-to-rest ratios of 1.0:0.5 (1, 22). In the women's game, players cover total distances between 1150-1800m, with relative demands between 75-115 m·min⁻¹ in just 14 min of play. Approximately 10-20% of the game is spent at high running speeds ($\sim \geq 5 \text{ m}\cdot\text{s}^{-1}$) with 30-50% of that distance spent at top speed ($\sim \geq 5.6 \text{ m}\cdot\text{s}^{-1}$). Average sprint distance between 15-22 m with maximum sprints of ~ 55 m in length and top speeds ranging from 6.8-7.9 m·s⁻¹ have also been observed (2, 4, 23). Approximately 75-85% of the game is played at heart rates greater than 80% of maximum with around a quarter of the game spent between 80-90% of maximum heart rate, and over half the game spent above 90% of maximum heart rate (2, 4, 23).

The majority of research performed on women's Sevens has examined domestic or national competitions such as continental championships or invitation tournaments (2, 4, 23). To date, only one study has examined game activity profiles of the top tier competition in the women's game (11). Higher level of women's competition has been shown to be associated with both greater absolute and relative game demands. Female players competing in international level competitions travel 17% greater total and relative distances in games. Average speed (+15%), peak speed (+12%), number of sprints (+75%), distance at top speed (+50%) and the distance covered in the highest speed bands (+40%) are all greater in higher level competitions (2). Players of higher standard also perform a greater number of high-intensity accelerations and decelerations (2, 4, 23). Physiological demands are also greater in international competition, characterized by 34% greater total time above 90% maximum heart rate (2).

Activity and physiological profiles vary with respect to a number of contextual game factors such as; physical characteristics of the athletes, positional group, opponent rank, score line, tournament day, game half, athlete rank, athlete playing time and game outcome (8, 11, 22, 23, 27, 28, 35). In men's Rugby Sevens, contextual factors have been found to affect running activity variables such as peak distance, relative distance, high-speed running distance, and the number of accelerations per minute of play (28). To date, no research has been conducted on the effect of contextual factors on international women's Rugby Sevens. It is important to have an understanding of top international-level competition and how the in-game profile changes with respect to game contextual factors. This information will not only inform training management of elite athletes but will support athletes in the developmental pathway of Rugby Sevens.

The aim of this study was to evaluate the activity and physiological profiles of international-level women's Rugby Sevens. Specifically, we aimed to describe the general profile of the game while also examining if differences existed in profiles between positional groups, game outcome, halves, tournament day, opponent rank and margin of victory.

4.3 Methods

4.3.1 Experimental Design

This study used an observational design across the five tournaments of the 2013-2014 World Rugby Women's Sevens World Series.

4.3.2 Participants

Twenty international-level female Rugby Sevens players (11 backs and 9 forwards; mean \pm SD, age 24.0 ± 3.6 years, height 168.4 ± 6.0 cm, mass 69.0 ± 5.0 kg) from the same national team participated in this study. The national team was a top three team in the 2013-2014 World Rugby Women's Series standings. All players received a clear explanation of the study and written consent was obtained from all participants. Ethical approval was obtained from the Australian Catholic University Human Ethics Research Committee.

4.3.3 Activity and Physiological Profiles

Global positioning system (GPS) data was collected at five World Rugby Women's Sevens Series events across the 2013-2014 season (Dubai, UAE; Sao Paulo, BRA; Atlanta, USA; Guangzhou,

CHN; Amsterdam, NED). Players wore GPS units sampling at 10 Hz (Minimax S4, Catapult Innovations, Australia) in fitted garments worn under their playing jerseys. The validity and reliability of 10 Hz GPS microtechnology has been confirmed previously (55). GPS units were activated and satellite lock established for a minimum of 15 minutes before each game commenced (average satellites locked during match = 12.1 ± 1.1 satellites/game). Data from the GPS units was classified into five velocity zones: low-speed: $0-0.2 \text{ m}\cdot\text{s}^{-1}$, moderate-speed: $0.2-3.5 \text{ m}\cdot\text{s}^{-1}$, high-speed: $3.5-5.0 \text{ m}\cdot\text{s}^{-1}$, very high-speed: $5.0-6.5 \text{ m}\cdot\text{s}^{-1}$ and top speed: $\geq 6.5 \text{ m}\cdot\text{s}^{-1}$. All activity data was reported as both absolute and relative (per minute) values. Player LoadTM (Catapult Innovations) was used as a measure of activity independent of distance in order to account for player accelerations in three different planes (anteroposterior, mediolateral, vertical) (56).

All players wore heart rate (HR) straps (T31, Polar Electro Oy, Finland) under their sport bras during matches that sampled at 1 Hz and were logged to the GPS device. Heart rate data was categorized into five zones (zone 1: 50-59% of heart rate max [HRmax], zone 2: 60-69% HRmax, zone 3: 70-79% HRmax, zone 4: 80-89% HRmax and zone 5: 90-100% HRmax). Maximum heart rate was determined prior to match analysis from 2 km time-trial and incremental exercise tests to exhaustion. Maximum heart rate values were updated if tested values were exceeded during match-play. Playing data was downloaded and then analyzed using a custom spreadsheet. For both activity and physiological data, non-playing minutes (half and bench time) were omitted from the analysis along with any data for players who did not play greater than 50% of total game time and at least 4 minutes of a half. Cup finals (10 min halves) were also excluded from the analysis.

4.3.4 Statistical Analysis

All activity and physiological profile data is reported as mean \pm SD. Percent differences in means are presented as percent difference; \pm CL. A linear mixed model in statistical analysis system (SAS) (Version 9.4: SAS Institute, Cary, NC) with the performance indicators as a fixed effect, a random effect for athletes, and an interaction effect for performance indicators and athletes was employed to characterize the relationship between the performance indicators and athletes. Significant variables ($p < 0.05$) were analyzed post hoc using a tukey procedure to correct for type I error in making multiple comparisons between parameters. Separate analyses were conducted for each of the following fixed effects; game half (first vs. second), playing position (forward vs. back), game outcome (wins vs. losses), tournament day (day 1 vs. day 2), opponent rank (top 4 world rank vs. bottom 4 world rank) and margin of victory or defeat (wins by ≥ 2 tries vs. losses by ≥ 2 tries). The standardized difference in the mean for contextual factors was also analyzed using Cohen's effect size statistic. Effect sizes (ES) of < 0.2 , $0.2-0.6$, $0.6-1.2$, $1.2-2.0$ and > 2.0 were considered trivial, small, moderate, large and very large, respectively (51). Magnitude-based inferences were also used to assess possible differences between contextual factors using the following qualitative probabilities: $< 1\%$ almost certainly not; 1% to 5% , very unlikely; 5% to 25% probably not; 25% to 75% possibly; 75% to 97.5% , likely; 97.5% to 99% , very likely; and $> 99\%$, most likely (51). A custom Excel work sheet (Version 14, Microsoft, USA) was used to calculate effect sizes, confidence intervals and magnitude based inferences (52).

4.4 Results

4.4.1 Game Data

Activity and physiological profiles for full games and positional groups (n = 191 game files) are presented in Table 4.1, while activity profiles for game outcome and halves are shown in Table 4.2. Compared to the second half (n = 216 game files), the first half (n = 193 game files) was most likely moderately longer in duration (p<0.001, 11.4; ±3.4%, ES = 0.7; 90% confidence limit ±0.3, 100%/0%/0%), with most likely moderate to larger total running distances (p<0.001, 20.1; ±4.0%, ES = 1.2; ±0.8, 100%/0%/0%), distances at moderate (p<0.001, 17.6; ±6.9%, ES = 1.0; ±0.4, 100%/0%/0%) and high running speeds (p<0.001, 24.5; ±7.8%, ES = 0.6; ±0.3, 100%/0%/0%) and very likely larger total Player LoadTM (p = 0.03, 19.0; ±5.1%, ES = 1.0; ±0.4, 96%/4%/0%). Time spent in heart rate zone 5 (90-100% HRmax) (p = 0.01, 16.4; ±14.5%, ES = 0.2; ±0.1, 87%/3%/10%) was likely higher in the second half versus the first half of play. The effect of contextual factors on activity profiles are shown in Figure 4.1.

Table 4.1. Activity and physiological profiles for international-level female Rugby Sevens players competing in the 2013-2014 World Rugby Women's Sevens World Series.

Variable	Full Game N = 191	Backs N = 103	Forwards N = 88
Mean Heart Rate (% of max)	88 ± 4	87 ± 3	87 ± 5
Mean Heart Rate (beats·m⁻¹)	170 ± 8	170 ± 7	169 ± 8
Heart Rate Zone 1·min⁻¹(%)*	1 ± 1	1 ± 1	1 ± 1
Heart Rate Zone 2·min⁻¹(%)*	2 ± 3	2 ± 3	2 ± 4
Heart Rate Zone 3·min⁻¹(%)*	10 ± 7	11 ± 7	9 ± 8
Heart Rate Zone 4·min⁻¹(%)*	40 ± 16	38 ± 14	39 ± 18
Heart Rate Zone 5·min⁻¹(%)*	49 ± 21	49 ± 18	50 ± 24
Total Distance (m)	1352 ± 306	1377 ± 280	1325 ± 332
Relative Distance (m·min⁻¹)	87 ± 11	86 ± 9	87 ± 12
Max Velocity (m·s⁻¹)	6.9 ± 0.8	7.1 ± 0.7	6.7 ± 0.7
Low-Speed Distance (m)	29 ± 14	28 ± 13	30 ± 14
Relative Low-Speed Distance (m·min⁻¹)	2 ± 1	2 ± 1	2 ± 1
Moderate-Speed Distance (m)	926 ± 214	949 ± 201	900 ± 225
Relative Moderate-Speed Distance (m·min⁻¹)	59 ± 7	59 ± 7	59 ± 8
High-Speed Distance (m)	255 ± 94	241 ± 80	269 ± 105
Relative High-Speed Distance (m·min⁻¹)	16 ± 5	15 ± 5	18 ± 6
Very High-Speed Distance (m)	112 ± 51	119 ± 50	104 ± 50
Relative Very-High Speed Distance (m·min⁻¹)	7 ± 3	8 ± 3	7 ± 3
Top Speed Distance (m)	38 ± 31	38 ± 34	31 ± 26
Relative Top Speed Distance (m·min⁻¹)	2 ± 2	2 ± 2	2 ± 2
Player Load TM(AU)	144 ± 34	147 ± 36	141 ± 34
Player Load TM min⁻¹(AU·min⁻¹)	9 ± 1	9 ± 2	9 ± 1

Data are Mean ± SD. Heart Rate Zone 1 50-59% HRmax, Heart Rate Zone 2 60-69% HRmax, Heart Rate Zone 3 70-79% HRmax, Heart Rate Zone 4 80-89% HRmax, Heart Rate Zone 5 90-100% HRmax, Low-Speed 0-0.2 m·s⁻¹, Moderate-Speed 0.2-3.5 m·s⁻¹, High-Speed 3.5-5.0 m·s⁻¹, Very High-Speed 5.0-6.5 m·s⁻¹, Top Speed ≥6.5 m·s⁻¹, AU = Arbitrary Units

* due to rounding % HR may not add to 100%

4.4.2 Game Outcome

Total running distance ($p < 0.001$, 11.4; $\pm 6.1\%$, ES = 0.6; ± 0.2 , 100%/0%/0%) and running distances at moderate- ($p < 0.001$, 6.1; $\pm 6.4\%$, ES = 0.3; ± 0.1 , 97.5%/0%/2.5%), high- ($p < 0.001$, 26.9; $\pm 9.7\%$, ES = 0.7; ± 0.4 , 98%/0%/2%) and very high-speed ($p = 0.02$, 26.0; $\pm 14.2\%$, ES = 0.7; ± 0.4 , 75%/2%/23%) were likely moderate to very likely larger during losses than wins (n = 191 game files).

4.4.3 Tournament Day

A likely trivial increase in activity profiles occurred from day one to day two of the tournament for total running distance ($p < 0.001$, 5.0; $\pm 5.3\%$, ES = 0.1; ± 0.1 , 1%/99%/0%) (n = 184 game files).

Table 4.2. Activity profiles for game halves and outcome for international-level female Rugby Sevens players competing in the 2013-2014 World Rugby Women's Sevens World Series.

Variable	First Half N = 193	Second Half N = 216	Effect Size (\pm CL)	Percentage Difference (\pm CL)	Qualitative Outcome	Wins N = 125	Losses N = 66	Effect Size (\pm CL)	Percentage Difference (\pm CL)	Qualitative Outcome
Total Distance (m)	776 \pm 118	640 \pm 180*	1.2 \pm 0.8	18.2 \pm 30.1%	Moderate	1312 \pm 290	1455 \pm 294**	0.6 \pm 0.2	10.9 \pm 1.4%	Moderate
Max Velocity (m·s⁻¹)	6.6 \pm 0.9	6.5 \pm 0.8	0.1 \pm 0.3	1.1 \pm 0.9%	Trivial	6.9 \pm 0.8	7.0 \pm 0.7	0.1 \pm 0.6	1.0 \pm 0.9%	Trivial
Low-Speed Distance (m)	15 \pm 10	14 \pm 9	0.1 \pm 0.3	1.0 \pm 0.8%	Trivial	28 \pm 14	30 \pm 12	0.1 \pm 0.3	1.0 \pm 1.5%	Trivial
Moderate-Speed Distance (m)	518.3 \pm 92	429.2 \pm 125*	1.0 \pm 0.4	17.7 \pm 24.5%	Moderate	913 \pm 208	964 \pm 204**	0.3 \pm 0.1	5.3 \pm 2.0%	Small
High-Speed Distance (m)	154 \pm 57	124 \pm 59*	0.6 \pm 0.3	19.5 \pm 4.4%	Moderate	237 \pm 87	295 \pm 97	0.7 \pm 0.4	19.7 \pm 11.0%	Moderate
Very High-Speed Distance (m)	69 \pm 36	54 \pm 31	0.1 \pm 0.3	21.8 \pm 15.5%	Trivial	104 \pm 42	133 \pm 59**	0.7 \pm 0.4	21.9 \pm 18.9%	Moderate
Top Speed Distance (m)	18 \pm 23	15 \pm 22	0.1 \pm 0.2	16.7 \pm 4.5%	Trivial	30 \pm 31	31 \pm 34	0.1 \pm 0.2	1.0 \pm 0.9%	Trivial
Player Load TM(AU)	84 \pm 18	69 \pm 20*	1.0 \pm 0.4	17.9 \pm 10.0%	Moderate	140 \pm 34	144 \pm 34	0.1 \pm 0.4	1.0 \pm 0.1%	Trivial

Data are Mean \pm SD, Low-Speed 0-0.2 m·s⁻¹, Moderate-Speed 0.2-3.5 m·s⁻¹, High-Speed 3.5-5.0 m·s⁻¹, Very High-Speed 5.0-6.5 m·s⁻¹, Top Speed \geq 6.5 m·s⁻¹, AU = Arbitrary Units

* denotes a significant difference between halves

** denotes a significant difference between outcome

4.4.4 Opponent Rank

Total running distance ($p < 0.001$, 12.6; $\pm 8.6\%$, ES = 0.6; ± 0.1 , 100%/0%/0%) and distances covered at moderate- ($p < 0.001$, 11.3; $\pm 8.5\%$, ES = 0.2; ± 0.1 , 100%/0%/0%) and high-speeds ($p = 0.02$, 15.5; $\pm 13.9\%$, ES = 0.1; ± 0.1 , 97%/0%/3%) were very to most likely trivial to moderately higher in games played against a top 4 opponent than a bottom 4 opponent ($n = 136$ game files).

4.4.5 Margin of Victory or Defeat

Total running distance ($p < 0.001$, 12.9; $\pm 8.8\%$, ES = 0.1; ± 0.1 , 61%/0%/39%) and distances covered at moderate- ($p = 0.001$, 6.8; $\pm 10.0\%$, ES = 0.1; ± 0.1 , 51%/0%/49%) and high-speeds ($p = 0.01$, 31.2; $\pm 14.9\%$, ES = 0.1; ± 0.1 , 72%/0%/28%) were possibly greater (trivial) when a loss was ≥ 2 tries compared to a win by the same margin ($n = 111$ game files).

4.4.6 Positional Group

No differences in activity or physiological profiles were identified based on playing position (backs vs. forwards) ($n = 191$ game files).

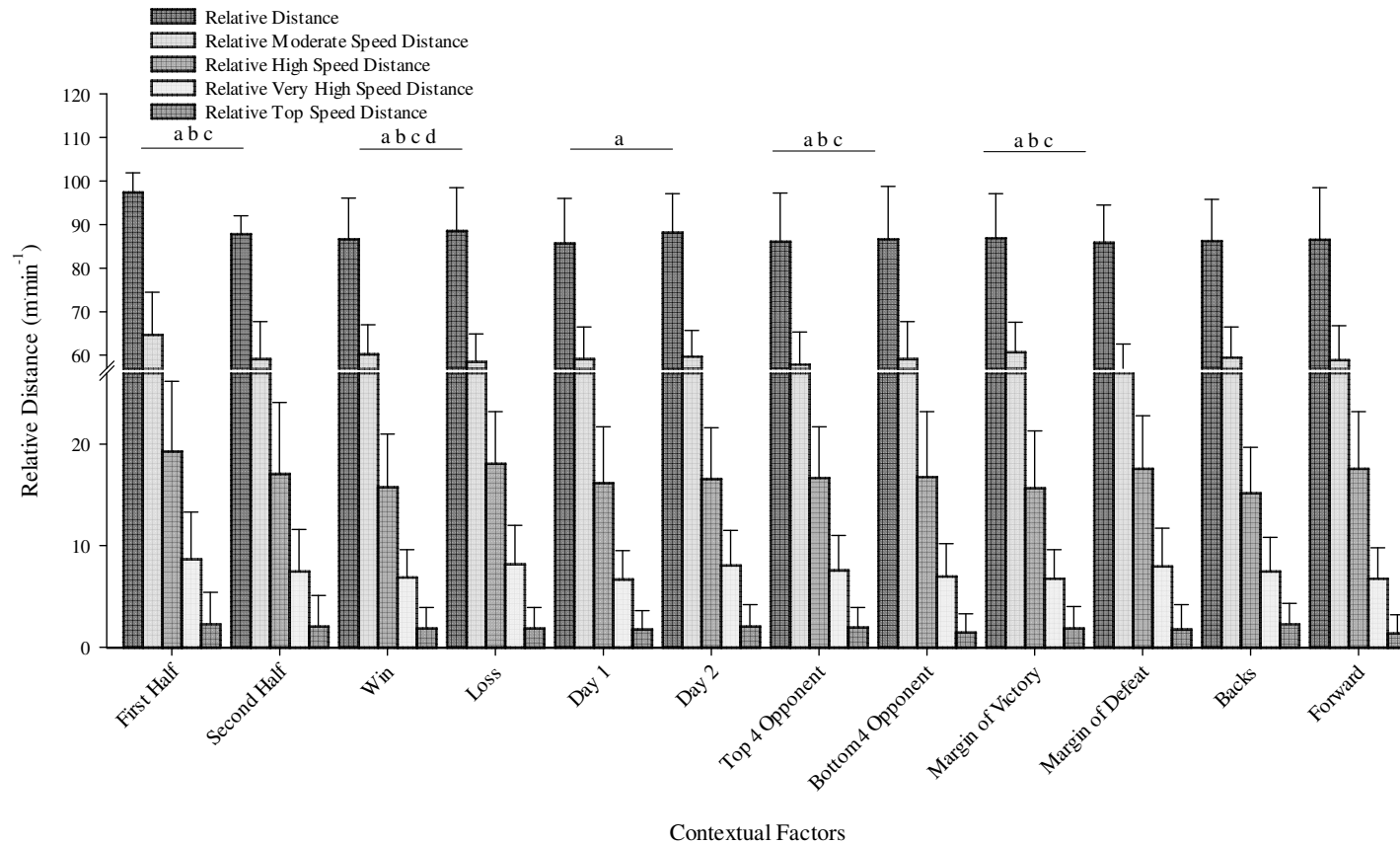


Figure 4.1. Differences in total, moderate, high, very high and top speed relative distances across multiple contextual factors for international women's Rugby Sevens.

a: significant difference ($p < 0.05$) in total distance, b: significant difference ($p < 0.05$) in moderate speed distance, c: significant difference ($p < 0.05$) in high-speed distance, d: significant distance ($p < 0.05$) in very high-speed distance

Low-Speed $0-0.2 \text{ m}\cdot\text{s}^{-1}$, Moderate-Speed $0.2-3.5 \text{ m}\cdot\text{s}^{-1}$, High-Speed $3.5-5.0 \text{ m}\cdot\text{s}^{-1}$, Very High-Speed $5.0-6.5 \text{ m}\cdot\text{s}^{-1}$, Top Speed $\geq 6.5 \text{ m}\cdot\text{s}^{-1}$

4.5 Discussion

This study is the first to investigate the activity and physiological profiles of international-level women's Rugby Sevens and determine the effect of various contextual factors (e.g. positional group, game half, tournament day, opponent rank, game outcome and final winning or losing margin) on these profiles over an entire playing season. Activity profiles were influenced by game half, tournament day, opponent rank, game outcome and final margin. Physiological profiles were influenced by game half. These findings suggest that contextual game factors influence activity profiles to a greater extent than physiological profiles. High-speed running ability is of importance to international women's Rugby Sevens players, suggesting that coaches and sport scientists should emphasize the development of this physical quality in their players.

A number of variables were affected by game half. The first half of women's Sevens games were characterized by greater activity demands compared to the second half with largely greater total distance and Player LoadsTM and moderately greater distances at moderate and high-speed. In the second half, small increases in physiological demand was observed with time spent above 90% of maximum heart rate greater than in the first half and reflective of increasing fatigue and cardiac drift late in the game. These results are in accordance with studies on both international women's and men's Rugby Sevens players (1, 2, 22, 24, 29). It is likely that the accumulation of fatigue in the first half, combined with a short half time interval (2 min), prevents complete recovery and results in players being unable to maintain activity levels from half to half. The accumulated fatigue and incomplete rest results in a subsequent greater physiological strain in the second half even with corresponding lower activity levels. Previous work in the same subject group has shown that measures of aerobic fitness differentiate playing minutes in elite women's Rugby Sevens (57)

with repeated-sprint ability differentiating playing rank in elite men's Rugby Sevens (35). Therefore, both a well-developed aerobic and anaerobic system appears to help international players resist fatigue during play, and improve recovery during play stoppage and half-time. This results in a better ability to maintain activity profiles from half to half, allowing players to play greater total minutes before requiring substitution.

Activity profiles were found to differ depending on tournament day. Total distance was increased on the second day of the tournament compared to day one. These results were found to be statistically significant yet the magnitude of differences were trivial, indicating that these findings are possibly of limited practical significance. Rugby Sevens is played in a tournament format where often six games are played across two days of competition. Pool play on day one re-seeds teams for day two finals competition. Tournament seeding in Rugby Sevens is such that a higher ranked team will be placed in a favorable pool position decreasing the likelihood of drawing more than one other top ranked team on day one. For the team studied, the average world rank of opponents on day one was 8th compared to a day two rank of 4th. A team can often suffer at least one defeat on day one and still compete for a top tournament placing, whereas a loss on day two will result in a lower finish and sometimes an early exit from the tournament. Countermovement jump height (as a measure of neuromuscular fatigue) and plasma creatine kinase concentrations (as an indirect measure of muscle damage) have been tracked across the course of both mens (58) (international tournament) and womens (59) (national tournament) Rugby Sevens tournaments. Peak power output and jump height during a countermovement jump were found to be suppressed from day 1 to day 2 in men but not in women. For both men and women, creatine kinase concentration was found to increase throughout the tournament. In male players, no decrement in

activity profiles were found between tournament days (1) indicating that the observed neuromuscular and muscular fatigue may not be reflected in reduced game activity. In female players, an increase in creatine kinase concentration was observed with a concurrent decrease in relative and high-speed distances covered with increasing distance covered at moderate-speeds (59) even with no observable change in countermovement jump variables. This may indicate that in females, peripheral muscular fatigue may contribute to decreases in activity levels. Clearly, further research investigating the influence of tournament match-play on the activity profiles of both male and female players is warranted.

Irrespective of game outcome, games against opponents of higher rank (i.e. top four in world rankings), resulted in moderately greater activity profiles than games against teams of lower rank (i.e. bottom four in world rankings). Playing against higher ranked teams resulted in both trivially greater total distances covered, and greater moderate and high-speed running distance. These results are similar to those found in international level men's Rugby Sevens (28) where greater distance covered and number of accelerations were found when playing teams of a higher rank. While others have found differences in activity profiles between different standard competitions, (13, 23) these findings demonstrate that meaningful differences in activity profiles also exist within the different tiers of the same competition. The greater total distances covered and distances at high running speeds may be a result of tactical game demands required to compete with top tier teams. It is also possible that in women's Rugby Sevens, there is a greater disparity between both the tactical and the physical abilities of top teams. These disparities may require greater activity profiles when playing against top teams in order to achieve a successful outcome. The team in this study had a 50% win rate against top ranked teams (ranked top 4 in the world), compared to a

100% win rate against bottom ranked teams (ranked in the bottom 4 in the world). It is possible that a strategic advantage could exist for teams drawing lower ranked teams in pool play on day one and final days of day two as the physical work required to play lower ranked teams is less, in theory saving the team for more physically demanding games against higher ranked opponents.

Losing game outcomes resulted in moderately greater total distance covered, and greater distances at moderate-, high- and very high-speeds. Furthermore, total distance and moderate- and high-speed running distance were trivially greater when a game was lost by a margin of two converted tries (14 points) compared to a game won by a similar margin. In international men's Rugby Sevens high-speed running did not relate to winning margins in tournament play (28). It was concluded that activity profiles might be affected more by the temporal relationship to game margin with higher profiles seen in games where score lines were close for extended periods of time. In Rugby League the effect of score line and winning and losing on activity profiles has been found to have equivocal results with some investigations finding greater running profiles in successful teams (33, 60) with others finding lower running profiles and greater collision demands in winning teams (61, 62). In international men's Rugby Sevens, successful teams maintain ball possession, score tries efficiently and complete a high percentage of tackles whereas less successful teams commit more game errors, take longer to score and miss more tackles (31). It is therefore possible that in international women's Rugby Sevens, efficient technical and tactical execution of the teams winning by a large margin (≥ 14 points) contributes to lower running activity profiles as they are able to control the game to a greater extent than teams who lose by a large margin (≥ 14 points). As with the men's game, it is also possible that losing women's teams miss

a greater number of tackles, increasing the need for players to cover-defend and pursue opposition players, thereby increasing the amount of high-speed running (61).

Trivial differences were found between playing positions for activity and physiological profiles, suggesting that game demands are homogenous for both backs and forwards in international women's Rugby Sevens. Physical characteristics have also been found to be similar between international women's Rugby Sevens playing positions (16), with only mass and sprint momentum differentiating playing position, lending further support to the generalist nature of women's Rugby Sevens. The lack of differences between positional groups is unique to the women's game as in the men's game significant differences exist between positional groups for both activity profiles (22, 27, 34) and physical characteristics (8). The fact that the men's game has been established as an international sport for a greater time than the women's game, may explain the higher degree of specialization in male players. The lack of positional differences in the women's Rugby Sevens players of this study may be a reflection of the evolving nature of the game in these players.

4.6 Conclusions

In women's Rugby Sevens, game half and game outcome, likely to most likely have moderate to large effects on activity profiles. Tournament day, opponent rank and margin of winning or losing all possibly to most likely affect activity profiles but in a trivial fashion. Only game half was found to have a likely small effect on physiological profiles. No differences in activity or physiological profiles were found between playing positions.

The greatest number of activity and physiological variables were affected by game half demonstrating that fatigue and lack of recovery in Rugby Sevens can lead to decreased movement ability and increased physiological strain in the second half of game play. This fatigue appears to be transient as activity levels increase as tournament play progresses, indicating that pacing might occur in earlier tournament games as players attempt to preserve energy for games of a higher standard that occur as the tournament progresses. This is supported by the findings of increased activity when playing against higher (top 4 world ranking) versus lower ranked (bottom 4 world rankings) opponents.

Game outcomes as well as the margin of outcome resulted in greater running distances at higher speeds; in women's Rugby Sevens losing teams have to run more at high-speed, most likely as a result of the quality of opponent and their own technical and tactical execution of play.

4.7 Practical Applications

High-speed running is the most common variable found to be linked to a number of contextual game factors in women's Rugby Sevens. It would be well advised for coaches and sport science practitioners to focus on enhancing this ability in women Rugby Sevens players. Also, as physiological and activity profiles change through the course of a game, training designed to replicate these changes would help prepare Sevens players for the in-game changes in activity and physiological strain. Talent identification and transfer programs should consider measuring high-speed running ability when assessing athletes for the sport of women's Rugby Sevens.

Chapter 5: Activity and Physiological Profiles of Winning and Losing and Attacking and Defensive Play in International Women's Rugby Sevens

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Goodale TL, Gabbett TJ, Tsai MC, Stellingwerff T. Activity and physiological profiles of winning and losing and attacking and defensive play in international women's Rugby Sevens. *International Journal Sports Physiology Performance*. Submitted for publication May 20, 2017.

5.1 Abstract

We investigated the effect of winning and losing, and attacking versus defensive play, on the physiological and activity profiles of international women's Rugby Sevens players. Eighteen international-level female Rugby Sevens players participated in this study. Global positioning system and heart rate data were collected at four World Rugby Women's Sevens Series events (2015-2016 season). Defensive periods were significantly longer ($p < 0.0001$, Effect Size [ES]= 0.1 ± 0.1) than attacking periods. Players covered significantly ($p < 0.0001$) greater distance (ES= 0.2 ± 0.1), high-speed distance (HSD; $\geq 3.5 \text{ m} \cdot \text{s}^{-1}$) (ES= 0.2 ± 0.2), relative distance ($\text{m} \cdot \text{min}^{-1}$; ES= 0.2 ± 0.2), relative HSD ($\text{m} \cdot \text{min}^{-1}$; ES= 0.2 ± 0.2), player load (PL) (ES= 0.2 ± 0.2) and relative PL (ES= 0.2 ± 0.2) in defense than attack. In attack, winning was associated with lower absolute distance ($p < 0.05$, ES= 0.1 ± 0.1), but greater relative distance ($p < 0.001$, ES= 0.2 ± 0.2) and relative HSD ($p < 0.0001$, ES= 0.2 ± 0.2). Winning defensive play was characterized by lower relative total distance ($p < 0.05$, ES= 0.3 ± 0.2) and HSD ($p < 0.001$, ES= 0.2 ± 0.2). In games won, players had greater ($p < 0.0001$) total distance (ES= 0.1 ± 0.1), relative distance (ES= 0.2 ± 0.2), HSD (ES= 0.2 ± 0.2), PL (ES= 0.2 ± 0.2) and relative PL (ES= 0.2 ± 0.2) in defense than attack. In women's Rugby Sevens, defensive play is physically more demanding than attack regardless of match outcome. Successful game outcomes are characterized by lower total running distances, with higher relative running distance in attack and lower total running distance in defense. Coaches and sport science practitioners should develop training plans to enhance the relative running abilities of Sevens players in order to support the greater demands of defensive play.

5.2 Introduction

Rugby Sevens is a high-intensity, intermittent, collision team sport (12, 63). The game consists of bursts of high-intensity activity (sprinting, high-speed running and tackling) separated by periods of lower-intensity activity (standing and low-speed running). Rugby Sevens is played in a tournament structure where 2-3 games are played per day over 2-3 days. Games are 14-minutes (two 7-minute halves separated by a 2-minute half-time) in duration and are typically separated by 2-4 hours. Teams are comprised of 12 players with players defined as either backs or forwards; positional groups have specific in-game duties relating to attack and defense as well as set pieces (line outs and scrums).

During international competition, women will typically cover ~1350 m with relative demands between 90 to 100 $\text{m}\cdot\text{min}^{-1}$; 30% of that distance is spent at high-speeds ($\geq 3.5 \text{ m}\cdot\text{s}^{-1}$). Approximately 90% of the game is played at heart rates greater than 80% of maximum heart rate, with close to 50% of the game spent above 90% of maximum heart rate (63). Game activity and physiological demands have been shown to vary with respect to contextual factors such as game half, game outcome and opponent rank (63). These contextual factors affect both absolute and relative ($\text{m}\cdot\text{min}^{-1}$) total distance and distance spent at high-speeds as well as time above 90% maximum heart rate (63).

In the very similar sport of Rugby League, the physical demands differ between defensive and attacking play (19). Defensive play had greater relative running demands, high-speed running distance, collision and repeated high-intensity effort frequency compared to attacking play (19).

The relative intensity of defensive play increased when teams were defending close to their opponent's try line, most likely in an attempt to secure favorable field position for future attacking play (19). The frequency of repeated high-intensity efforts increased when teams were either defending their own try line or attacking their opponent's try line (19).

Examinations of men's Rugby Sevens have demonstrated that a high rate of tackle completions and maintaining possession to score more points results in successful game outcomes (31). In the men's game, it has also been shown that players participate in anywhere between 3 to 15 tackles per game (0.2 to 1.0 tackle per minute of play) with forwards performing a greater proportion of tackles than backs (22, 31). Investigations into the relationships between physical qualities and tactical play in men's Rugby Sevens has found that properties such as acceleration and top-speed running ability, initial-sprint momentum, lower-body power, upper-body pulling strength and repeated-sprint ability relate positively to defensive play (12). From these initial examinations unique relationships and differences exist specific to the tactical phase of play in Rugby Sevens. It therefore stands to reason that other differences and relationships with respect to tactical play may exist.

To date, no study has examined the relationship between tactical phase of play, game demands and contextual factors in women's international Rugby Sevens. The interaction between in-game tactical play, game demands and game outcomes are typically multi-factorial. Therefore, the aim of this study was to investigate the activity and physiological profiles of winning and losing, and attacking and defensive play in international women's Rugby Sevens.

5.3 Methods

5.3.1 Experimental Design

An observational design was used to assess activity and physiological profiles for attacking and defensive play in games won and lost in international women's Rugby Sevens players.

5.3.2 Participants

Eighteen international-level female Rugby Sevens players (mean \pm SD, age 24.6 ± 3.1 years, height 169.0 ± 7.6 cm, mass 71.9 ± 7.3 kg) from the same national team participated in this study. This national team was a world-class program, as they were a top three team in the 2015-2016 World Rugby Women's Sevens World Series standings and earned a bronze medal at the 2016 Olympic Games. All players received a clear explanation of the study and written consent was obtained from all participants. Ethical approval was obtained from the Australian Catholic University Human Ethics Research Committee.

5.3.3 Activity and Physiological Profiles

Global positioning system (GPS) data was collected at four World Rugby Women's Sevens World Series events across the 2015-2016 season (Sao Paulo, BRA; Atlanta, USA; Victoria, CDN; Clermont-Ferrand, FRA). Players wore GPS units sampling at 10 Hz (Minimax S4, Catapult Innovations, Australia) in fitted garments worn under their playing jerseys. The validity and reliability of 10 Hz GPS micro-technology has been confirmed previously (55). GPS units were activated and satellite lock established for a minimum of 15 minutes before each game commenced

(average satellites locked during match = 12.0 ± 1.5 satellites/game). Data from the GPS units was classified into three velocity zones: standing ($0-0.2 \text{ m}\cdot\text{s}^{-1}$), low-speed ($0.2-3.5 \text{ m}\cdot\text{s}^{-1}$) and high-speed ($\geq 3.5 \text{ m}\cdot\text{s}^{-1}$). Activity data was reported as both absolute and relative (per min) values. Player LoadTM (Catapult Innovations) was also used as a measure of activity to account for player accelerations in three different planes (anteroposterior, mediolateral, vertical) (56).

During matches, all players wore heart rate (HR) straps (T31, Polar Electro Oy, Finland) that sampled at 1 Hz and were logged to the GPS device. Maximum heart rate was determined prior to match analysis from 1.6 km time-trial and incremental exercise tests to exhaustion. Maximum heart rate values were updated if tested values were exceeded during match-play. Playing data was downloaded and then analyzed using a custom spreadsheet. Attacking and defensive work periods were manually coded during game play and via video review. For both activity and physiological data, all non-playing time (referee stoppage, ball-out-of-play, half and bench time) were omitted from the analysis.

5.3.4 Statistical Analysis

All activity and physiological profile data is reported as mean \pm standard deviation (SD). Differences in means are presented as percent difference; \pm confidence limit (CL). Independent sample t-tests were used to identify GPS and HR variables that were significantly different between attacking and defensive play, game outcome (wins vs. losses), and for run time and ball-in-play time using R (Version 3.31: Vienna, Austria). Changes were assessed using the standardized difference in the mean, Cohen's *d* effect size statistic. Effect sizes (ES) of <0.2 , $0.2-$

0.6, 0.6-1.2, 1.2-2.0 and >2.0 were considered trivial, small, moderate, large and very large, respectively (51). A custom Excel work sheet (Version 14, Microsoft, USA) was used to calculate effect sizes and confidence intervals (52).

5.4 Results

The activity and physiological profiles and general game descriptive statistics for ball-in-play and total game time (including ball-out-of-play) are shown in Table 5.1 and 5.2.

Table 5.1. Activity and physiological profiles comparing run time and ball-in-play time in international-level female Rugby Sevens players competing in the 2015-2016 World Rugby Women’s Sevens World Series.

Variable	Full Game Run Time N = 222	Full Game Ball-in-Play N = 3145
Mean Heart Rate (% of max)	83 ± 7	81 ± 13
Relative Distance (m·min⁻¹)*	96 ± 14	143 ± 53
Relative Low-Speed Distance (m·min⁻¹)*	64 ± 9	78 ± 30
Relative High-Speed Distance (m·min⁻¹)*	32 ± 9	64 ± 64
Relative Player LoadTM (AU·min⁻¹)*	10 ± 2	18 ± 7

Data are Mean ± SD. CL = 90% Confidence Limits. Low-Speed (0.2-3.5 m·s⁻¹), High-Speed (≥3.5 m·s⁻¹),

AU = Arbitrary Units

*Significant difference at p≤0.05

Table 5.2. General game descriptive statistics for ball-in-play and dead ball time in international-level female Rugby Sevens players competing in the 2015-2016 World Rugby Women’s Sevens World Series.

Variable	Time N = 222
Game duration excluding half (s)	900 ± 60
Ball-in-play time (s)	420 ± 60
Dead ball time (s)	480 ± 60
Average ball-in-play cycle (s)	33 ± 22
Average ball-out –of playball cycle (s)	41 ± 25

Data are Mean ± SD.

When compared to attacking periods, defensive periods were longer in duration ($p < 0.0001$, ES = 0.1; ± 0.1), with players covering greater distance ($p < 0.0001$, ES = 0.2; ± 0.1), high speed distance ($p < 0.0001$, ES = 0.2; ± 0.2), relative distances ($p < 0.0001$, ES = 0.2; ± 0.2) and relative high speed distance ($p < 0.0001$, ES = 0.2; ± 0.2). Players also had higher relative player loads ($p < 0.0001$, ES = 0.2; ± 0.2) in defense than attack (Table 5.3 and 5.4).

Table 5.3. Activity and physiological profiles for attacking and defensive play in international-level female Rugby Sevens players competing in the 2015-2016 World Rugby Women's Sevens World Series.

Variable	Attack N = 1604	Defense N = 1537	Effect Size (\pmCL)	Qualitative Outcome
Mean Heart Rate (% of max)	82 \pm 13	83 \pm 12	0.0 \pm 0.1	Trivial
Relative Distance (m\cdotmin⁻¹) *	137 \pm 56	148 \pm 51	0.2 \pm 0.1	Small
Relative Low-Speed Distance (m\cdotmin⁻¹)	77 \pm 32	79 \pm 29	0.1 \pm 0.1	Trivial
Relative High-Speed Distance (m\cdotmin⁻¹) *	60 \pm 64	69 \pm 64	0.2 \pm 0.2	Small
Relative Player LoadTM (AU\cdotmin⁻¹) *	17 \pm 7	18 \pm 6	0.2 \pm 0.2	Small

Data are Mean \pm SD. CL = 90% Confidence Limits. Low-Speed (0.2-3.5 m \cdot s⁻¹), High-Speed (\geq 3.5 m \cdot s⁻¹), AU = Arbitrary Units

*Significant difference at $p \leq 0.05$

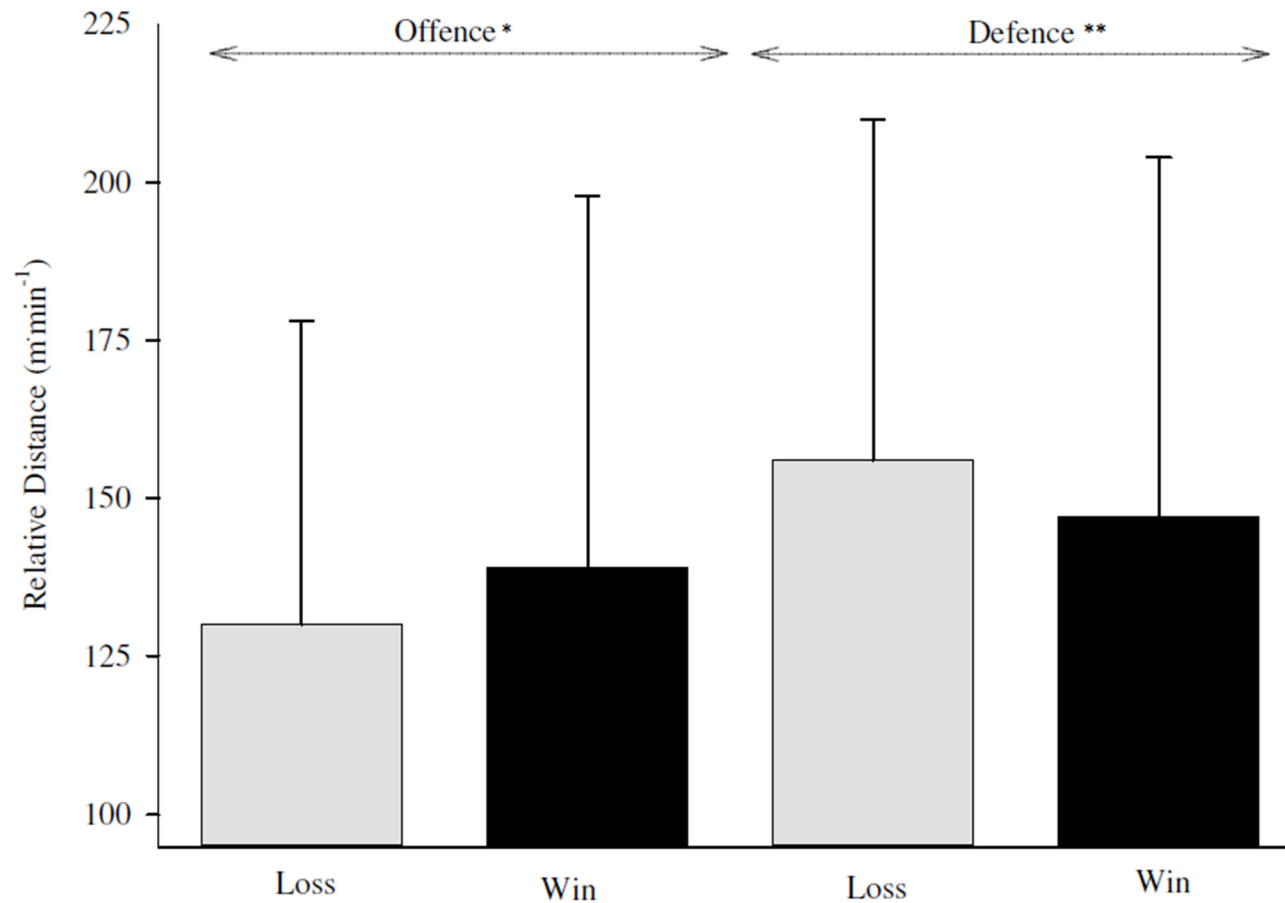


Figure 5.1. Differences in relative distance covered in wins and losses on attack and defense in international-level female Rugby Sevens players competing in the 2015-2016 World Rugby Women’s Sevens World Series.

*Significant difference at $p \leq 0.05$

**Significant difference at $p \leq 0.05$

In games won ($N = 19$), activity in attack was characterized by less absolute distance ($p < 0.05$, $ES = 0.1; \pm 0.1$), and greater relative distance ($p < 0.001$, $ES = 0.2; \pm 0.2$), relative high-speed distance ($p < 0.0001$, $ES = 0.2; \pm 0.2$), and relative player load ($p < 0.01$, $ES = 0.2; \pm 0.2$) compared to attacking play during losses ($N = 5$). Conversely, in defense, winning was characterized by players covering less relative distance ($p < 0.05$, $ES = 0.3; \pm 0.2$), high-speed distance ($p < 0.001$, $ES = 0.2; \pm 0.2$) and relative high-speed distance ($p < 0.001$, $ES = 0.2; \pm 0.2$) (Figure 5.1 and 5.2). Comparing defensive to attacking play in games won, players had greater total distance ($p < 0.0001$, $ES = 0.1; \pm 0.1$), relative distance ($p < 0.001$, $ES = 0.2; \pm 0.2$), high-speed distance ($p < 0.001$, $ES = 0.2; \pm 0.2$), player loads ($p < 0.0001$, $ES = 0.2; \pm 0.2$) and relative player loads ($p < 0.0001$, $ES = 0.2; \pm 0.2$).

Table 5.4. Activity and physiological profiles for attacking and defensive play comparing game outcome in international-level female Rugby Sevens players competing in the 2015-2016 World Rugby Women’s Sevens World Series.

Variable	Attack				Defense			
	Win N = 1252	Lose N = 352	Effect Size (\pm CL)	Qualitative Outcome	Win N = 1117	Lose N = 420	Effect Size (\pm CL)	Qualitative Outcome
Mean Heart Rate (% of max)	82 \pm 12	83 \pm 14	0.1 \pm 0.1	Trivial	83 \pm 13	83 \pm 12	0.1 \pm 0.1	Trivial
Relative Distance (m·min ⁻¹)	139 \pm 59*	130 \pm 4*	0.2 \pm 0.2	Small	147 \pm 50*	156 \pm 54*	0.3 \pm 0.2	Small
Relative Low-Speed Distance (m·min ⁻¹)	77 \pm 32	79 \pm 28	0.1 \pm 0.1	Trivial	80 \pm 30	76 \pm 28	0.1 \pm 0.1	Trivial
Relative High-Speed Distance (m·min ⁻¹)	62 \pm 68*	50 \pm 49*	0.2 \pm 0.2	Small	65 \pm 62	76 \pm 6	0.2 \pm 0.2	Small
Relative Player Load TM (AU·min ⁻¹)	17 \pm 7*	16 \pm 6*	0.2 \pm 0.2	Small	18 \pm 6	19 \pm 6	0.1 \pm 0.1	Trivial

Data are Mean \pm SD. CL = 90% Confidence Limits. Low-Speed (0.2-3.5 m·s⁻¹), High-Speed (\geq 3.5 m·s⁻¹), AU = Arbitrary Units

*Significant difference at $p \leq 0.05$

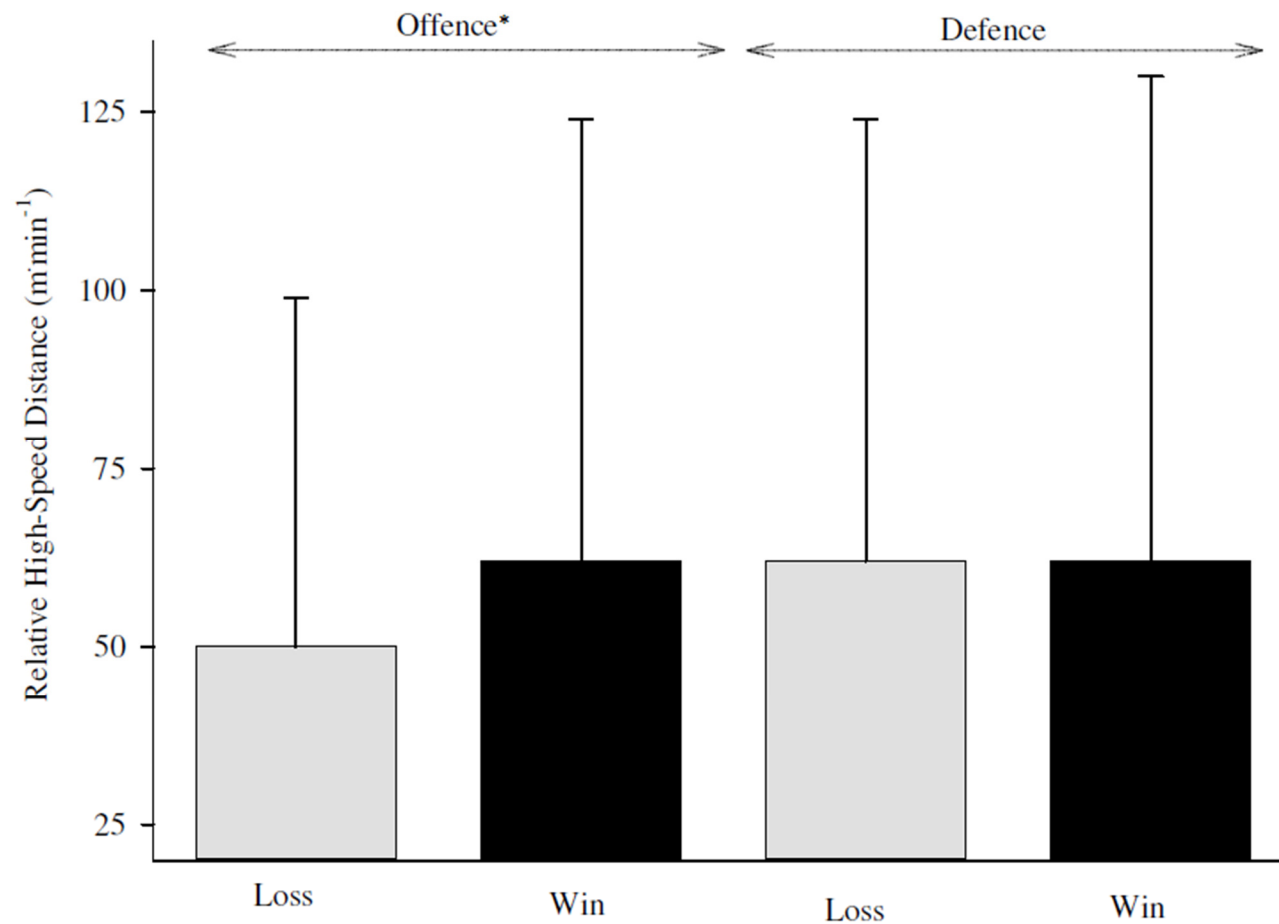


Figure 5.2. Differences in relative high-speed distance covered in wins and losses on attack and defense in international-level female Rugby Sevens players competing in the 2015-2016 World Rugby Women’s Sevens World Series.

*Significant difference at $p \leq 0.05$

5.5 Discussion

This study is the first to examine the effect of winning and losing and attack versus defense on the physiological and activity profiles in international-level women's Rugby Sevens. Defensive play was found to be physically more demanding than attacking play with players covering significantly greater total distance, total high speed distance, relative distance and relative high speed distance while accumulating greater player loads and relative player loads. In games won compared to games lost, attacking play was characterized by less total distance with greater relative distance and high speed distance, coupled with greater relative player load. Defensive play in games won was characterized by lower total high speed distance, relative distance and relative high speed distance than in games lost. These results suggest that activity profiles differ between tactical phases of play in international women's Rugby Sevens, with defense requiring greater activity than attack. In both attack and defense, winning style of play is characterized by less total running, with winning attacking play having greater relative running intensities.

These findings are consistent with those from Rugby League, whereby the physical demands of defense were also found to be greater than in attack (19). Relative distance, low speed distance (off ball movement), frequency of collisions and repeated high-intensity efforts were all greater in defense (19). In men's Rugby Sevens, ball possession has been found to relate to tries scored and tournament performance, suggesting that teams that maintain ball possession, or regain possession quickly, have more opportunities to score and therefore are more successful (31). Rugby sevens is typically played on a field 100 m long x 70 m wide. Defensive structures will typically see 6 to 7 players defending as a single line starting anywhere from 1 to 10 m away from the attacking team. The amount of space to cover in conjunction with ball possession needed to score requires teams

to defend with greater total and relative demands than they attack in order to stop attacking teams from scoring and in an attempt to gain ball possession. With so few players on the field, and the greater space available to attacking players, it is also possible that the ball is able to cover more distance as with the greater amount of space there are increased opportunities to shift the ball via passing as oppose to running, leading to greater running demands in defense. In Rugby Sevens, as with other rugby codes, defending is associated with greater physical loads and therefore specific conditioning and running drills should be designed with this in mind.

Winning tactical play was characterized by both greater total and high-speed relative demands. In games won, players covered less total distance in attack, but at greater relative running and relative high-speed running demands. This highlights that in order to support successful game outcomes, attacking play needs to be played at a high relative pace and at high speeds. Defensive play in successful games was both efficient, with less distance covered, and less intense, with lower relative intensities than in losing efforts. In games won, defense was still more physically demanding than attack, further highlighting the greater physical load of defending. These findings are supported by previous research on women's Rugby Sevens that indicated that total running distance was greater in losses compared to wins (63). In international men's Rugby Sevens, successful teams maintained ball possession, scored efficiently and completed more tackles (31). Conversely, less successful teams committed more game errors, took longer to score and missed more tackles (31). As defense is found to be more physically demanding than attack, efficient attacking play may support the ability to play defense at higher intensities as athletes are taxed less physically by attacking play and are therefore able to perform more work in defense. Defensively it is also possible that losing women's teams also make errors and miss a greater number of tackles,

increasing the need for players to cover-defend and pursue opposition players, thereby increasing the total amount of running performed in losing efforts (62).

Coding only ball-in-play game time compared to game run time resulted in a 50% increase in relative running demands, a 100% increase in relative high-speed demands and an 80% increase in relative player load. Similar results have been found in Rugby League, as greater relative demands were found when dead ball time was eliminated from game analysis (19). In international women's Rugby Sevens the ball is only in play for less than 47% of the total game time, with average ball-in-play time lasting approximately 30 s with average dead ball time lasting around 40 s. Consistent with the study on professional men's Rugby League, the present study provides a more accurate representation of the active demands of international women's Rugby Sevens match-play. Our current analysis also demonstrates that there is approximately 25% more dead ball time between each ball-in-play cycle showing that on average, players have a greater amount of time to recover between periods of play, than the average length of play itself. Drills designed to mimic the worst-case scenario with respect to work to rest ratios, could be designed with work periods based on ball-in-play time with rest periods based on dead ball times.

Large variations (as indicated from standard deviations) in ball-in-play time were also found. Ball-in-play time varies largely due to stoppages in play as a result of defensive pressure, penalties or handling errors. The number of trivial to small effects found in this study could be due to this large variation. Similar results have been found in semi-elite Rugby League competition (33, 61, 62)

and the emerging nature of women's Rugby Sevens could lend itself to the similarities found in these results.

5.6 Conclusions

In international women's Rugby Sevens, defense was found to be more demanding than attack irrespective of game outcome. Attacking play in successful game outcomes was characterized by less total running distance performed at high intensities and speeds. In absolute and relative terms, defensive teams work less when they win compared to when they lose. Relative distance and relative high-speed distance are physical metrics that relate to attacking and defensive play and successful game outcomes, highlighting the ability of players to cover more distance at higher velocities per unit of time.

5.7 Practical Applications

As attack and defense in women's Rugby Sevens have differing physical demands, teams should design specific conditioning drills to address the specific needs of Rugby Sevens tactical play. The development of high levels of both relative running and relative high-speed running skills during both attack and defense are key to successful game outcomes. This suggests the requirement of Rugby Sevens players to have a high-level of aerobic conditioning, coupled with the ability to attain and repeat high peak speeds. Monitoring the intensity of running activities in training is therefore recommended to coaches and practitioners in order to ensure training is of an adequate intensity to stimulate adaptation in players.

Coding only ball-in-play time as opposed to total game time is recommended in order to better understand the active demands of women's Rugby Sevens. Failing to eliminate dead ball time could lead to an underestimation of active game demands and the possibility of not preparing players for the true "in-play" demands of the game. Understanding the range of in-play and dead ball time can also help practitioners design worst case scenario work to rest training interventions.

**Chapter 6: The Relationship between Physical Qualities, Physiological and Activity Profiles
and Contextual Factors in International Women's Rugby Sevens**

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Goodale TL, Gabbett TJ, Tsai MC, Stellingwerff T, Sheppard JM. The relationship between physical qualities, physiological and activity profiles and contextual factors in international women's Rugby Sevens. *International Journal Sports Physiology Performance*. Submitted for publication March 25, 2017.

6.1 Abstract

We evaluated the relationship between physical qualities, physiological and activity profiles and contextual factors in international-level women's Rugby Sevens players. Sixteen international-level female Rugby Sevens players from the same national team participated in this study. Players underwent measurements of anthropometry, speed, repeated-sprint ability, lower-body power, critical speed and aerobic fitness. Global positioning system and heart rate data were collected at five World Rugby Women's Sevens Series events (2014-2015 season). Relative distance ($p < 0.05$, $ES = 0.3; \pm 0.2$) and relative high-speed distance (HSD) ($\geq 3.5 \text{ m}\cdot\text{s}^{-1}$) ($p < 0.001$, $ES = 0.3; \pm 0.1$) were significantly associated with match outcome (wins or losses). Relative distance ($p < 0.001$, $ES = 0.4; \pm 0.1$), relative HSD ($p < 0.05$, $ES = 0.2; \pm 0.2$) and relative player load (PL) ($p < 0.01$, $ES = 0.3; \pm 0.1$) were associated with margin of defeat. Relative HSD ($p < 0.05$, $ES = 1.1; \pm 0.7$), mean heart rate ($p < 0.05$, $ES = 0.5; \pm 0.4$) and time $\geq 90\%$ heart rate max ($p < 0.05$, $ES = 0.6; \pm 0.4$) were associated with margin of victory. Relative HSD ($p < 0.01$, $ES = 0.3; \pm 0.1$) and relative PL ($p < 0.05$, $ES = 0.3; \pm 0.1$) were associated with playing position. Physical qualities such as aerobic fitness, repeated-sprint ability, maximal running velocity and critical-speed were related to physiological and activity demands. Game outcome and margin are affected by greater physiological and relative activity profiles. Differences exist between playing positions for activity profiles. Repeated-sprint ability, maximal running velocity, aerobic fitness and critical speed are significantly associated with game demands, outcome and margin as well as playing position. Coaches should develop repeated-sprint ability and aerobic fitness in order to prepare women's Rugby Sevens players for on-field success.

6.2 Introduction

Several studies have investigated the physical characteristics and activity profiles of Rugby Sevens players (11, 13, 15, 16, 57, 59, 64-66). Lower-body power, aerobic fitness, maximal running velocity and upper-body strength, have been found to relate to various aspects of Rugby Sevens such as playing standard, training adaptation and activity profiles (16, 35, 57, 59). An understanding of players' physical characteristics and their relationship to various in-game factors can inform training prescription and talent identification pathways for Rugby Sevens.

During international competition, women will cover ~1350m with relative demands between 90-100 $\text{m}\cdot\text{min}^{-1}$; 30% of that distance is spent at high-speeds ($\geq 3.5\text{m}\cdot\text{s}^{-1}$). Approximately 89% of the game is played at heart rates greater than 80% maximum heart rate (%HRmax) with close to 50% of the game spent above 90% HRmax (63). Game activity and physiological demands can vary with respect to contextual factors such as game half, game outcome, game margin, opponent rank, and tournament day (63). These contextual factors have affected both absolute and relative total distance and distance spent at high-speeds, acceleration counts and time above 90% HRmax (63).

Recently, investigators have examined the link between player physical characteristics and game demands or tactical execution (10, 12). In international and national male Rugby Sevens players, running speed, lower-body power and repeated-sprint ability have shown relationships to in-game tactical outcomes such as line breaks, defenders beaten, tackles, tries scored, work rate and handling errors (12). For this study, data was combined for international and national playing levels; it is therefore possible that different relationships exist depending on level of play as it has been shown that physical characteristics and game demands vary between standard of play (10,

12). In international female players, age, mass, running speed, and lower-body power were related to game activity profile variables such as impacts, absolute distance, absolute high-speed distance, relative distance, sprint distance, accelerations, and maximal speed (10). As testing was conducted across sexes, playing standard, and age groups the physical tests used to sample these populations were limited to field tests that could be administered across a diverse athletic population (10).

To date, no study has examined the relationship between female player physical characteristics, game demands and contextual factors. As the interaction between athlete physical abilities and in-game metrics and game factors are typically multi factorial, the aim of this study was to investigate the relationship between player physical characteristics and activity and physiological profiles in relation to various contextual factors such as positional group, game outcome and game margin in international women's Rugby Sevens players.

6.3 Methods

6.3.1 Experimental Design

An observational design was used to assess physical characteristics and their relationship with activity and physiological profiles with respect to contextual demands in international women's Rugby Sevens players. Players underwent a comprehensive physical testing battery three to four times during the general preparatory and competitive phases of the 2014-2015 World Rugby Women's Sevens Series training cycle. Only testing data collected within (\pm) 21 days of a tournament was used for analysis.

6.3.2 Participants

Sixteen international level female Rugby Sevens players (8 backs and 8 forwards; mean \pm SD, age 24.3 ± 2.8 years, height 167.5 ± 5.6 cm, mass 70.2 ± 6.4 kg) participated in this study. Players were from a top two team in the 2014-2015 World Rugby Women's Sevens World Series (WSWS). All players received a clear explanation of the study and written consent was obtained from all participants. Ethical approval was obtained from the Australian Catholic University Human Ethics Research Committee.

6.3.3 Activity and Physiological Profiles

Global positioning system (GPS) data was collected at five World Rugby WSWS events (30 total games) across the 2014-2015 season (Dubai, UAE; Sao Paulo, BRA; Atlanta, USA; Victoria, CDN; London, ENG). Players wore GPS units sampling at 10 Hz (Minimax S4, Catapult Innovations, Australia) in fitted garments under their playing jerseys (55). Data from the GPS units was classified into three velocity zones: standing ($0-0.2 \text{ m}\cdot\text{s}^{-1}$), low-speed ($0.2-3.5 \text{ m}\cdot\text{s}^{-1}$), high-speed ($\geq 3.5 \text{ m}\cdot\text{s}^{-1}$) (12). All activity data was reported as relative (per minute) values. Player LoadTM (Catapult Innovations) was used as a measure of activity independent of distance in order to account for player accelerations in three different planes (anteroposterior, mediolateral, vertical) (56).

All players wore heart rate (HR) straps (T31, Polar Electro Oy, Finland) during matches that sampled at 1 Hz. Heart rate data was categorized into five zones (zone 1: 50-59% of heart rate max [HRmax], zone 2: 60-69% HRmax, zone 3: 70-79% HRmax, zone 4: 80-89% HRmax and zone 5: 90-100% HRmax). Maximum HR was determined prior to match analysis from 1.6 km

time-trial and incremental exercise tests to exhaustion. Maximum HR values were updated if tested values were exceeded during match-play. For activity and physiological data, non-playing minutes were omitted from the analysis along with any data for players who did not play greater than 20% of total game time.

6.3.4 Physical Characteristics

6.3.4.1 Anthropometry

Stature was measured to the nearest 0.5 cm using a stadiometer (Tanita, Japan) and body mass was measured to 0.01 kg using a calibrated digital scale (Avery Berkel, UK).

6.3.4.2 Speed

Running speed was assessed using a 40 m sprint with splits obtained at the 10, 30 and 40 m mark using wireless electronic timing gates (Brower Timing Systems, USA). Athletes started from a two-point stance 0.75 m from the start line. Three attempts were given to produce a best effort with 5 minutes rest between attempts. The fastest 40 m value and its corresponding 10 and 30 m split were recorded. Average velocities for the 0-10 m split and the 30-40 m split were multiplied by the athlete's mass to calculate initial sprint momentum (ISM) and maximal sprint momentum (MSM). The intraclass-coefficients (ICC) for 10, 30, 40 m, ISM and MSM are $r=0.90$, $r=0.95$, $r=0.96$, $r=0.96$ and $r=0.97$, respectively.

6.3.4.3 Lower-Body Muscular Power

Lower-body muscular power was estimated using a standing long jump (SLJ) and a standing triple-long jump (STJ) for maximum horizontal distance. Athletes started behind the start line straddling a measuring tape affixed to the ground. Athletes were allowed a countermovement and 3 attempts per jump with 5 minutes rest between attempts. For the STJ, players maintained continuity between all three jumps while landing each jump on both feet. The ICC for SLJ and STJ are $r=0.93$ and $r=0.96$, respectively.

6.3.4.4 Aerobic Fitness

Maximal oxygen consumption ($\dot{V}O_{2max}$) testing was performed on a motorized treadmill (Woodway, USA). After a 10 min warm up the protocol comprised a submaximal stage followed by incremental running to exhaustion. Players completed 5 to 8 x 3 min stages with a 30 sec rest period to allow for collection of blood lactate samples and rating of perceived exertion (RPE). Running speed increased by $0.8 \text{ km}\cdot\text{hr}^{-1}$ per stage; the initial testing stage started at a self-selected easy run pace (1% gradient). The 3 min stages continued until blood lactate concentrations $\sim 4 \text{ mmol}\cdot\text{l}^{-1}$ were attained. The maximal portion of the test comprised 1 min stages where either running speed ($0.8 \text{ km}\cdot\text{hr}^{-1}$) or gradient increased (1%) occurred until voluntary exhaustion ($\dot{V}O_{2max}$). Heart rate and expired air ventilation were recorded throughout the test and peak blood lactate samples were taken 3 min post-exhaustion. The ICC for the $\dot{V}O_{2max}$ test was $r=0.98$.

6.3.4.5 Critical Speed

A 3 minute all out-running test around a 400 m track was completed to assess critical speed (CS). Players wore GPS units sampling at 10 Hz (Minimax S4, Catapult Innovations, Australia) in fitted garments. Subjects were instructed to sprint as hard as possible from the start of the test until told to stop. Subjects were instructed to stop once 3 min and 5 s had elapsed, ensuring that a full 3 min were recorded. Verbal encouragement was given but no feedback was provided on time to prevent pacing. The average speed between the 150 s and 180 s mark was used as the CS value ($\text{m}\cdot\text{s}^{-1}$). This test has recently been validated in comparison to other time trial tests (ICC $r=0.65-0.87$) (67).

6.3.4.6 Repeated-Sprint Ability

Repeated-sprint ability (RSA) was assessed using a 10 x 40 m repeated-sprint test. Athletes started from a two-point stance 0.75 m back from the start line and were instructed to run as quickly as possible until past the final gate. 40 m sprints were repeated on a 30 s turnaround; athletes were required to walk 20 m out and back to the start line between 40 m sprints. 40 m times were collected using wireless electronic timing gates (Brower Timing Systems, USA). The sum of the ten 40 m sprints was used for analysis. The ICC for the 10 x 40 m repeated-sprint test was $r=0.92$.

6.3.5 Statistical Analysis

All physical characteristics, activity and physiological profile data are reported as mean \pm SD. Differences in means are presented as percent difference; \pm CL. Independent sample t-test was used

to identify GPS and HR variables that were significantly different between game outcome (wins vs. losses) and position (forward vs. back), while ANOVA was used to identify the GPS and HR variables that were significantly different in margin of victory or defeat (wins by ≥ 2 tries vs. losses by ≥ 2 tries) using R (Version 3.31: Vienna, Austria). A binomial logistic regression was used to identify the variables that were associated with the contextual factors (game outcome, position and margin of victory or defeat) using R (Version 3.31: Vienna, Austria). A linear mixed model in statistical analysis system (SAS) (Version 9.4: SAS Institute, Cary, NC) with the identified GPS and HR variables as a fixed effect and a random effect for athlete physical characteristics was employed to characterize the relationship between the GPS, HR and player physical qualities. Separate analyses were conducted for each of the following fixed effects; playing position (forward vs. back), game outcome (wins vs. losses) and margin of victory or defeat (wins by ≥ 2 tries vs. losses by ≥ 2 tries). Changes were assessed using the standardized difference in the mean, Cohen's *d* effect size statistic. Effect sizes (ES) of <0.2 , $0.2-0.6$, $0.6-1.2$, $1.2-2.0$ and >2.0 were considered trivial, small, moderate, large and very large, respectively (51). A custom Excel work sheet (Version 14, Microsoft, USA) was used to calculate effect sizes and confidence intervals (52).

6.4 Results

The physical characteristics of players are presented in Table 6.1. Activity profiles for margin of victory ($n = 188$ game files) or defeat ($n = 59$ game files) are shown in Table 6.2.

Table 6.1. Descriptive and comparative statistics of physical characteristics for international women's Rugby Sevens players competing in the 2014-2015 World Rugby Women's Sevens World Series.

Variable	Team	Backs	Forwards
	N = 16	N = 8	N = 8
$\dot{V}O_{2max}$ (l·min ⁻¹)	3.3 ± 0.4	3.2 ± 0.3	3.6 ± 0.3
Critical Speed (m·s⁻¹)	3.6 ± 0.4	3.5 ± 0.4	3.7 ± 0.5
10x40m Sum (s)	63.1 ± 3.3	61.8 ± 1.9	64.4 ± 4.0
10m Time (s)	1.8 ± 0.1	1.8 ± 0.1	1.9 ± 0.1
30m Time (s)	4.4 ± 0.1	4.4 ± 0.1	4.5 ± 0.2
40m Time (s)	5.6 ± 0.2	5.5 ± 0.2	5.7 ± 0.2
30-40m Time (s)	1.2 ± 0.1	1.2 ± 0.1	1.2 ± 0.1
Initial Speed Momentum (kg·m·s⁻¹)	393.2 ± 32.7	370.2 ± 21.4	416.3 ± 24.7
Maximal Speed Momentum (kg·m·s⁻¹)	571.9 ± 58.1	530.5 ± 39.7	613.4 ± 41.6
Standing Long Jump (cm)	228.6 ± 9.6	232.1 ± 9.2	224.5 ± 9.1
Standing Triple Jump (cm)	697.2 ± 36.4	707.4 ± 24.6	692.3 ± 46.3

Data are Mean ± SD, $\dot{V}O_{2max}$ = maximal aerobic power

Backs achieved higher maximum velocities ($p < 0.001$, ES = 0.3; ±0.2), had higher mean HR ($p < 0.0001$, ES = 0.4; ±0.2), covered greater relative distance at high-speed ($p < 0.001$, ES = 0.3; ±0.2), and had greater relative player loads ($p < 0.0001$, ES = 0.4; ±0.2) than forwards (Table 6.1). Binomial logistic regression identified an association between playing position and relative high-speed distance ($p < 0.01$, ES = 0.3; ±0.1) and relative player load ($p < 0.05$, ES = 0.3; ±0.1). Relative high-speed distance was related to repeated-sprint ability (10 x 40 m sum) ($p < 0.01$, ES = 1.4; ±0.7) while relative player load was related to $\dot{V}O_{2max}$ ($p < 0.05$, ES = 0.9; ±0.7).

In games won, players had greater relative total distance ($p < 0.0001$, $ES = 0.5; \pm 0.2$), relative high-speed distance ($p < 0.01$, $ES = 0.3; \pm 0.2$) and relative player loads ($p < 0.05$, $ES = 0.3; \pm 0.2$) than games lost (shown in Table 6.2). Binomial logistic regression identified an association between game outcome and relative total distance ($p < 0.05$, $ES = 0.3; \pm 0.2$) and relative high-speed distance ($p < 0.001$, $ES = 0.3; \pm 0.1$). Relative total distance covered was related to $\dot{V}O_{2\max}$ ($p < 0.05$, $ES = 1.1; \pm 0.7$). Relative high-speed distance was associated with repeated-sprint (10 x 40 m sum) performance ($p < 0.05$, $ES = 1.0; \pm 0.7$).

Table 6.2. Activity and physiology profiles for position and outcome for international women's Rugby Sevens players competing in the 2014-2015 World Rugby Women's Sevens World Series.

Variable	Backs N = 157	Forwards N = 90	Effect Size (±CL)	Qualitative Outcome	Wins N = 186	Loses N = 61	Effect Size (±CL)	Qualitative Outcome
Relative Distance (m·min ⁻¹)	96.5 ± 18.0	95.3 ± 23.5	0.1 ± 0.2	Trivial	98.1 ± 19.9**	95.6 ± 19.7**	0.5 ± 0.2	Small
Relative High-Speed Distance (m·min ⁻¹)	32.9 ± 13.7*	30.8 ± 15.2*	0.3 ± 0.2	Small	33.3 ± 14.7**	31.6 ± 12.6**	0.3 ± 0.2	Small
Relative Player LoadTM (AU·min ⁻¹)	11.0 ± 2.3*	10.1 ± 2.3*	0.4 ± 0.2	Small	11.0 ± 2.3**	10.2 ± 2.2**	0.3 ± 0.2	Small
Mean HR (% of max)	86.4 ± 6.9*	84.9 ± 6.4*	0.4 ± 0.2	Small	86.2 ± 7.1	85.1 ± 6.2	0.3 ± 0.2	Small
Time Above 90% Max HR (min)	5.9 ± 4.3	5.5 ± 4.4	0.1 ± 0.1	Trivial	5.6 ± 4.4	6.0 ± 4.3	0.2 ± 0.2	Small
Max Velocity (m·s ⁻¹)	6.9 ± 0.9*	6.6 ± 1.0*	0.3 ± 0.2	Small	6.7 ± 0.9	6.9 ± 0.9	0.1 ± 0.2	Trivial

Data are Mean ± SD, High-Speed ≥ 3.5 m·s⁻¹, CL = 90% Confidence Limits, HR = Heart Rate, AU = Arbitrary Units

* denotes a significant difference (P<0.05) between positions

** denotes a significant difference (P<0.05) between outcome

In games won by ≥ 2 tries compared to those won by < 2 tries, players covered greater relative high-speed distance ($p < 0.05$, ES = 0.4; ± 0.2) had a higher mean HR ($p < 0.05$, ES = 0.5; ± 0.2) and spent less time above 90% Max HR ($p < 0.05$, ES = 0.5; ± 0.2) (Table 6.3). Binomial logistic regression identified relative high-speed distance ($p < 0.05$, ES = 0.6; ± 0.4), higher mean HR ($p < 0.05$, ES = 0.5; ± 0.4) and time above 90% Max HR ($p < 0.05$, ES = 0.6; ± 0.4) as having an association with margin of victory. Relative high-speed distance covered ($p < 0.05$, ES = 1.1; ± 0.7) and time spent above 90% Max HR ($p < 0.05$, ES = 1.0; ± 0.4) were related to repeated-sprint ability (10 x 40 m sum) while time spent above 90% Max HR was also related to maximum running velocity (30-40 m split) ($p < 0.05$, ES = 0.3; ± 0.3). Mean HR was related to critical speed ($p < 0.05$, ES = 1.2; ± 0.6).

Table 6.3. Activity and physiology profiles for margin of victory or defeat for international women's Rugby Sevens players competing in the 2014-2015 World Rugby Women's Sevens World Series.

Variable	Wins \geq 2T N = 98	Wins < 2T N = 88	Effect Size (\pm CL)	Qualitative Outcome	Loses \geq 2T N = 14	Loses < 2T N = 45	Effect Size (\pm CL)	Qualitative Outcome
Relative Distance ($\text{m}\cdot\text{min}^{-1}$)	100.6 \pm 19.3	97.3 \pm 20.4	0.4 \pm 0.2	Small	94.9 \pm 12.3❖	87.9 \pm 21.3❖	0.5 \pm 0.3	Small
Relative High Speed Distance ($\text{m}\cdot\text{min}^{-1}$)	34.7 \pm 12.8♦	31.8 \pm 16.5♦	0.5 \pm 0.2	Small	32.6 \pm 8.9❖	29.6 \pm 13.6❖	0.4 \pm 0.2	Small
Relative Player LoadTM ($\text{AU}\cdot\text{min}^{-1}$)	11.2 \pm 2.4	10.8 \pm 2.2	0.2 \pm 0.1	Small	10.8 \pm 1.9❖	10.2 \pm 2.3❖	0.3 \pm 0.2	Small
Mean HR (% of max)	86.5 \pm 5.4♦	85.9 \pm 6.3♦	0.5 \pm 0.2	Small	84.4 \pm 5.5	85.4 \pm 7.1	0.2 \pm 0.2	Small
Time Above 90% Max HR (min)	5.4 \pm 4.9♦	6.2 \pm 4.7♦	0.4 \pm 0.2	Small	5.9 \pm 3.6	6.5 \pm 4.4	0.1 \pm 0.2	Trivial
Max Velocity ($\text{m}\cdot\text{s}^{-1}$)	6.8 \pm 0.7	6.6 \pm 1.1	0.2 \pm 0.1	Small	6.8 \pm 0.8	7.0 \pm 1.0	0.1 \pm 0.1	Trivial

Data are Mean \pm SD. High-Speed \geq 3.5 $\text{m}\cdot\text{s}^{-1}$, CL = 90% Confidence Limits, HR = Heart Rate, AU = Arbitrary Units

♦ denotes a significant association ($P < 0.05$) with margin of victory

❖ denotes a significant association ($P < 0.05$) with margin of defeat

In games lost by ≥ 2 tries compared to those lost by < 2 tries players covered greater relative distance ($p < 0.0001$, ES = 0.5; ± 0.2) and relative high-speed distance ($p < 0.001$, ES = 0.4; ± 0.2) and had greater relative player loads ($p < 0.01$, ES = 0.3; ± 0.2) (Table 6.3). Binomial logistic regression identified relative distance ($p < 0.001$, ES = 0.4; ± 0.1), relative player loads ($p < 0.01$, ES = 0.3; ± 0.1) and relative high-speed distance ($p < 0.05$, ES = 0.2; ± 0.2) as being associated with margin of defeat. Relative distance covered ($p < 0.05$, ES = 1.2; ± 0.5) and relative player load ($p < 0.05$, ES = 1.2; ± 0.5) were related to aerobic fitness ($\dot{V}O_{2\max}$). Relative high-speed distance covered was related to repeated-sprint (10 x 40 m sum) performance ($p < 0.05$, ES = 1.0; ± 0.6). Figure 6.1 provides an overview of the significant relationships between player physical qualities, activity and physiological profiles, and contextual factors in international women's Rugby Sevens.

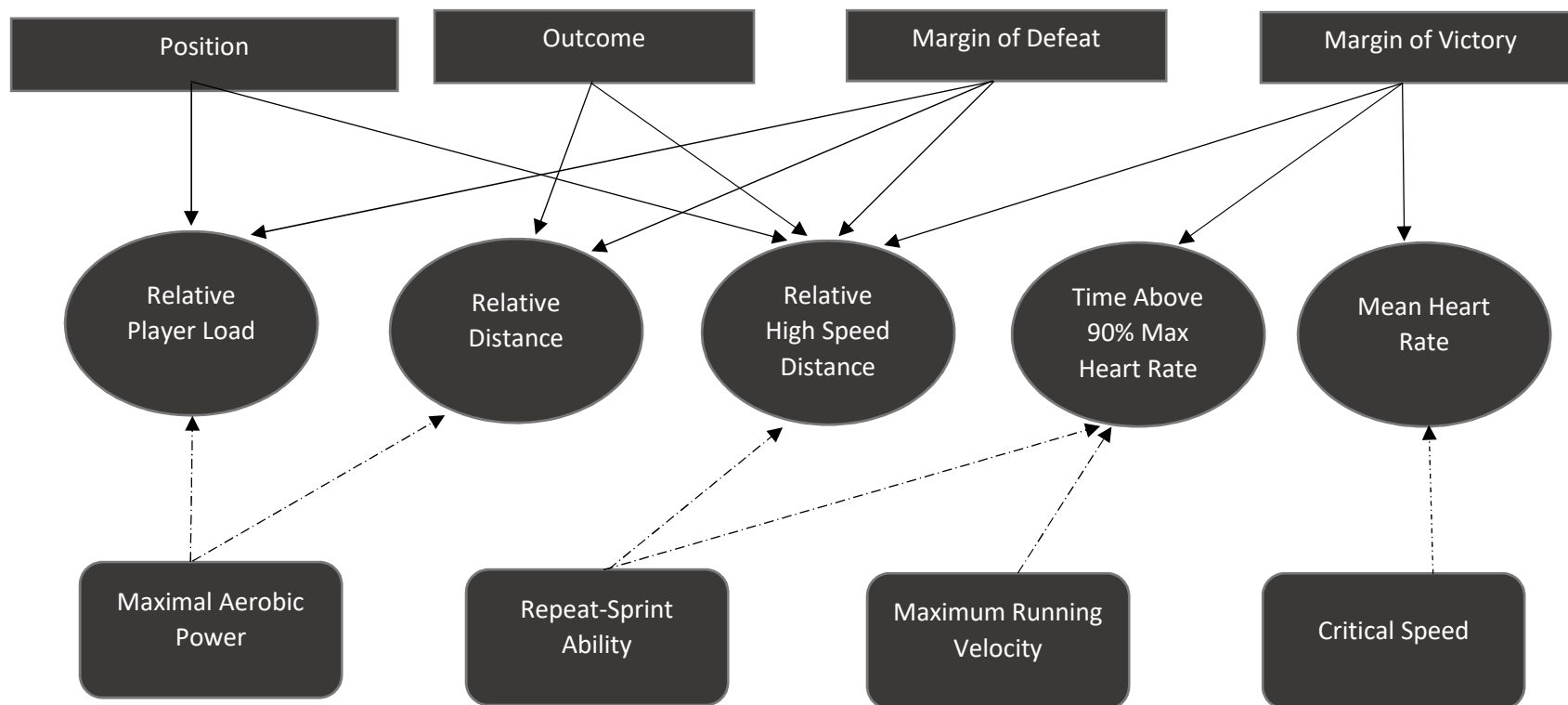


Figure 6.1. Relationship between contextual factors, physiological and activity profiles and physical qualities in international women's Rugby Sevens.

6.5 Discussion

This study is the first to investigate the relationship between physical qualities, activity and physiological profiles and contextual factors in international-level women's Rugby Sevens over multiple international tournaments. Both total and high-speed relative running distances, relative player load and HR indices were influenced by playing position, game outcome and final game margin. Aerobic fitness, repeated-sprint ability, maximum running velocity and critical speed were all related to activity and physiology profiles. These findings suggest that relative running outputs and acceleration and deceleration movements along with HR responses are influenced by both contextual factors and physical qualities. Relative high-speed running ability is of importance to international women's Rugby Sevens players and is influenced by repeated-sprint ability suggesting the development of this physical quality be prioritized in players.

Players covered greater relative distance and relative high-speed distance in games won indicating that both running distance and distance at higher velocities is important for a successful game result. Recent research on international women's Rugby Sevens has shown that total running distances were greater in losses compared to wins (63). Data for this study showed a similar trend for absolute running distances, as games lost were typically 1 min longer in total duration possibly due to attempts by losing teams to keep the ball in play after game time had expired in a last effort to win. In the present study it appears that the intensity of running, rather than the total running performed, was the most important factor contributing to successful game outcomes. In international men's Rugby Sevens, successful teams maintained ball possession, scored efficiently and completed more tackles (31). Conversely, less successful teams committed more game errors, took longer to score and missed more tackles (31). It is possible that losing women's teams also

make errors and miss a greater number of tackles, increasing the need for players to cover-defend and pursue opposition players, thereby increasing the total amount of running performed (61).

Final game margin affected both activity and physiological profiles. Players covered greater relative distance and had greater relative player loads in losses of large margins as well as covering greater relative high-speed distance in both losses and wins of large margins. Therefore, points scored appear to be related to running intensity. In international men's Rugby Sevens, points scored were found to be related to greater ball possession and fewer turnovers, penalties, kicks and passing (31). As score line is related to teams maintaining ball possession and passing less, players will be required to run to move the ball due to less passing and kicks (31). Attacking players are required to break defensive lines by running at greater relative intensities in attacking patterns requiring the opposing team to react by accelerating and running to cover and chase down offensive players that have broken the defensive line. In Rugby League, game margin was found to be affected by player activity profiles with winning teams having greater relative running demands and losing teams having greater relative high-speed demand (60).

Greater average HR response was also related to margin of victory, possibly as a result of the greater relative activity demands. Although the average HR response was greater, time above 90% HRmax was lower in games won by a greater margin. As HR is affected by more than just physical activity it is possible that other internal and external factors such as hydration status and ambient temperature affect physiological responses aside from running activity (68).

Relative distance and player load were related to aerobic fitness while relative high-speed distance was related to repeated-sprint ability, indicating that players with these qualities were able to cover more distance, accelerate, decelerate and run at higher speeds per minute of match-play. In high-intensity intermittent team sports a well-developed aerobic system aids recovery between repeated high-intensity bouts, as well as facilitates recovery between multiple matches over a two-day tournament (8, 53). Aerobic fitness has been found to differentiate players of national and international playing standard in women's Rugby Sevens (57). Furthermore, male Rugby Sevens players with greater repeated-sprint ability were involved in more defensive game actions and committed fewer game errors (12), while players with better repeated-sprint ability were involved in more offensive and defensive game actions per minute of play in 15-a-side Rugby Union (69). In Soccer players, those with greater repeated-sprint ability covered greater high-speed distances during match-play (70). Rugby League players with greater repeated-sprint ability covered greater high-speed distance than those with less developed repeated-sprint ability (71). With only 7 players per side and 14 total players on the field at any one time in a game of Rugby Sevens, there is far greater total distance available per player to perform game movements, possibly allowing athletes to reach higher running velocities to successfully complete in-game tactical movements. The ability to repeatedly run at high velocities (average repetition velocity of $6.4 \text{ m}\cdot\text{s}^{-1}$ during the 10 x 40 m repeated-sprint test) appears to facilitate a player's ability to cover greater relative high-speed distance ($> 3.5 \text{ m}\cdot\text{s}^{-1}$), possibly due to a speed reserve and the ability to repeat high-speed runs on a relatively short turnaround of 30 s.

Time above 90% HRmax was related to both repeated-sprint ability and maximal running velocity. Maximal running velocity has been found to be a determinant of repeated-sprint performance in

Soccer players (72). The inter-relationship between maximal running velocity and repeated-sprint ability indicates that faster athletes are also able to repeatedly run at higher intensities, necessitating a greater physiological response from the aerobic system to support the maintenance of the repeated high-intensity work, especially as the number of repeat sprints increases (73, 74). Mean HR was related to a players' critical speed, (i.e. the cut off velocity above which aerobic pathways can no longer sustain running intensity). Running at velocities above critical speed requires a greater contribution from anaerobic energy systems. Although more validated in endurance sports, we hypothesize that athletes with higher critical speeds are able to recover quicker between plays and then work at higher intensities during critical game moments. The interplay between physiological and movement demands can therefore be seen as a balance between higher-intensity anaerobic abilities such as maximal running velocity and repeated-sprint ability and lower-intensity aerobic abilities such as critical speed and $\dot{V}O_{2max}$.

6.6 Conclusions

In women's Rugby Sevens, game outcome, margin of defeat and playing position were related to activity profiles. Margin of victory was associated with both relative activity and physiological profiles. Relative-high speed distance was the activity profile most commonly related to contextual factors, highlighting the importance of players being able to cover more distance at higher velocities per unit of time. Teams that are able to run harder are able to score more frequently and win more in the process.

Repeated-sprint ability, maximal running velocity, $\dot{V}O_{2\max}$ and critical speed were all related to game activity and physiological profiles. Repeated-sprint ability and $\dot{V}O_{2\max}$ were the physical qualities most commonly related to in-game demands. Having well-developed anaerobic and aerobic fitness appears to contribute to an athlete's ability to work harder in international women's Rugby Sevens, which in turn supports a team's ability to score and win more.

6.7 Practical Applications

Relative distance and relative high-speed distance covered are two variables related to a number of outcome-related contextual factors in women's Rugby Sevens. Aerobic fitness, critical speed, repeated-sprint ability and maximal running velocity were related to a player's ability to perform the relative demands of Rugby Sevens. Enhancing these physical qualities through an integrated training approach should be a focus for coaches and sport science practitioners working with female Rugby Sevens players. Talent identification and transfer programs should consider assessing aerobic fitness, critical speed, repeated-sprint ability and maximal running velocity when assessing potential athletes for the sport of women's Rugby Sevens.

Chapter 7: Summary and Conclusions

7.1 Overview

This program of research investigated the relationship between physical qualities, contextual factors and activity and physiological profiles in international women's Rugby Sevens. The research first identified gaps in the body of knowledge on women's Rugby Sevens through a review of the existing literature. Four research studies were conducted to address the identified gaps in the literature on women's Rugby Sevens (Table 7.1).

Table 7.1. Summary of study outline, aims, and experimental hypotheses.

Chapter in Thesis	Study Outline	Aims	Experimental Hypotheses
Chapter 2	Narrative Review	Assess the current state of the literature with respect to international women's Rugby Sevens	Limited scientific data on women's Rugby Sevens will be present since its recent introduction to international play
Chapter 3	Profile the physical qualities of elite female Rugby Sevens players and differentiate higher- and lesser-skilled performers	Relationship between physical characteristics and selection between international and national female Rugby Sevens Players	Elite performers will demonstrate superior physical qualities to Sub-Elite performers and these physical differences will contribute to their playing selection
Goodale TL, Gabbett TJ, Stellingwerff T, Tsai MC, Sheppard JM. Relationship between physical qualities and minutes played in international women's rugby sevens. <i>Int J Sports Physiol Perform.</i> 2016;11(4):489-494.			
Chapter 4	Game demands in relation to position, game half, outcome and opponent rank	Effect of contextual factors and their relationship between physiological and activity profiles of the international game of women's Rugby Sevens	Differences in the specific physiological and activity demands of the international game will exist for a variety of contextual factors such as playing position, game half, game outcome, and opponent rank
Goodale TL, Gabbett TJ, Tsai MC, Stellingwerff T, Sheppard J. The Effect of contextual factors on physiological and activity profiles in international women's rugby sevens. <i>Int J Sports Physiol Perform.</i> 2016:1-21.			
Chapter 5	Demands of attacking and defensive play and their relationship to game outcome	Differences in physiological and activity profiles based on the tactical phase of game; attack versus defense	Differences in physiological and activity profiles will exist relating to tactical phase of play and in relation to game outcome
Goodale TL, Gabbett TJ, Tsai MC, Stellingwerff T, Sheppard J. The Effect of contextual factors on activity and physiological profiles of attacking and defensive play in international women's rugby sevens. <i>Submitted for publication to Int J Sports Physiol Perform.</i> May 2017.			
Chapter 6	Interrelationship between player qualities, contextual factors and game demands	Relationship between contextual factors, physical characteristics and the physiological and activity profile of women's Rugby Sevens players	Multiple relationships will exist between measures of physical abilities, contextual factors and specific game demands
Goodale TL, Gabbett TJ, Tsai MC, Stellingwerff T, Sheppard J. The Relationship between physical qualities, physiological and activity profiles and contextual factors in international women's rugby sevens. <i>Submitted for publication to Int J Sports Physiol Perform.</i> Mar 2017.			

7.2 Summary of Major Findings

Table 7.2 summarizes the study outline, aims, and experimental hypotheses. Expanding on this summary:

- (i) *It was hypothesized that limited research on women's Rugby Sevens would be available for practitioners to base informed training decisions upon.* As Rugby Sevens was only admitted in 2009 to the Olympic Games program, chapter 2 demonstrates that limited research had been conducted on the game leading into its first Olympic quadrennial. Limited research existed on the game in general and specifically with respect to the women's game. At the time of undertaking this series of research projects only three studies on women's Rugby Sevens had been conducted (2, 4, 10) with only one study examining international level players (10). Therefore, the hypothesis of being able to identify gaps within the existing literature was supported
- (ii) *In Chapter 3, it was hypothesized that physical qualities would differentiate playing rank between international and national caliber players.* By examining the relationship between physical testing and playing minutes across an international season various physical qualities were found to relate to playing selection, which is similar to the men's game (35). General qualities such as age and training experience along with physical qualities of upper-body strength and aerobic fitness differentiated selection in international women's' Rugby Sevens. The existence of physical quality differences between two difference levels of representation in women's Rugby Sevens resulted in the hypothesis being largely supported.
- (iii) *Chapter 4 examined physiological and activity demands specific to the international game of women's Rugby Sevens. It was hypothesized that differences would*

exist in physiological and activity profiles with respect to various contextual factors. Microtechnology data collected across a complete season of international women's Sevens were used to examine the relationship between physiological and activity profiles and contextual factors; game half, game outcome, tournament day, opponent rank, game margin, and positional group. Physiological and activity profiles were found to decrease between halves in women's Rugby Sevens. Activity demands were found to differ with relation to game outcome, tournament day, opponent rank and margin of victory with high-speed running being the most common variable linked to these contextual factors. Unlike the men's game, no in-game differences were found between playing position, indicating similar demands exist regardless of playing position. Partial support was identified for the hypothesis of contextual factors influencing physiological and game activity profiles.

(iv) *Chapter 5 details the investigation into the relationship between tactical phase of play, activity and physiological profiles and game outcome. It was hypothesized that differences would exist between tactical phases and that there would also be differences in these variables relating to game outcome.* Defensive play was found to be more physically demanding than attack, with greater relative total running and high-speed running values. In games won, players covered less total relative distance with a greater percentage of that relative distance performed at high-speeds on attack. It was also determined that interpretation of game demands is dependent upon how this data is coded. Exclusion of ball-out-of-play lead to far greater relative running demands than previously reported. The hypothesis was largely supported by some but not all variables showing differences between game outcome and tactical phases, game activity and physiological profiles.

(v) *The final project (Chapter 6), investigated the relationship between player physical qualities, in-game demands and contextual factors in international women’s Rugby Sevens. It was hypothesized that fitter and faster players would be able to play at greater game intensities and that this would result in successful game outcomes.* Physical testing and physiological and activity demand data across a season of international women’s Sevens was examined in relation to contextual factors; game outcome, game margin and playing position. Relative running intensity, high-speed running intensity, and heart rate indices such as time above 90% maximum heart rate and mean heart rate were related to playing position, game outcome, and game margin. Physical qualities such as aerobic fitness, critical speed, repeated-sprint ability and maximum running velocity underpinned players’ abilities to perform at higher in-game physiological and activity demands. The results strongly supported the hypothesized influence of selected physical qualities on successful game outcomes.

Table 7.2. New findings that contribute to the field of women’s Rugby Sevens.

Chapter in Thesis	New Contributions to the Field
Chapter 3	<ul style="list-style-type: none"> - The following player characteristics contributed to playing selection in international women’s Rugby Sevens <ul style="list-style-type: none"> o Age o Training experience o Upper-body strength <ul style="list-style-type: none"> ▪ Bench Press ▪ Pull Up o Aerobic fitness <ul style="list-style-type: none"> ▪ 1600m time trial
Chapter 4	<ul style="list-style-type: none"> - Players were unable to maintain similar activity profiles between halves in international women’s Rugby Sevens - Players were able to recover between tournament days and maintained similar game activity profiles - Players ran more in losses than wins and ran more when the margin of defeat was greater - High-speed running was the most common variable linked to a range of contextual factors
Chapter 5	<ul style="list-style-type: none"> - Defense was physically more demanding than attack independent of game outcome - Winning attacking tactical play was played at greater relative physical intensities than losing attacking play

	<ul style="list-style-type: none"> - Game demands were dependent on game coding techniques; coding only ball-in-play time can help to better understand the active game demands of Rugby Sevens
Chapter 6	<ul style="list-style-type: none"> - Running intensity and high-speed running intensity were important physical activities that support successful game outcome - In games, physical differences in demands existed between playing position in international women's Rugby Sevens - Important player physical qualities to develop in international women's Sevens players to best support successful game outcomes included: <ul style="list-style-type: none"> o Aerobic fitness o Critical speed o Maximum running velocity o Repeated-sprint ability

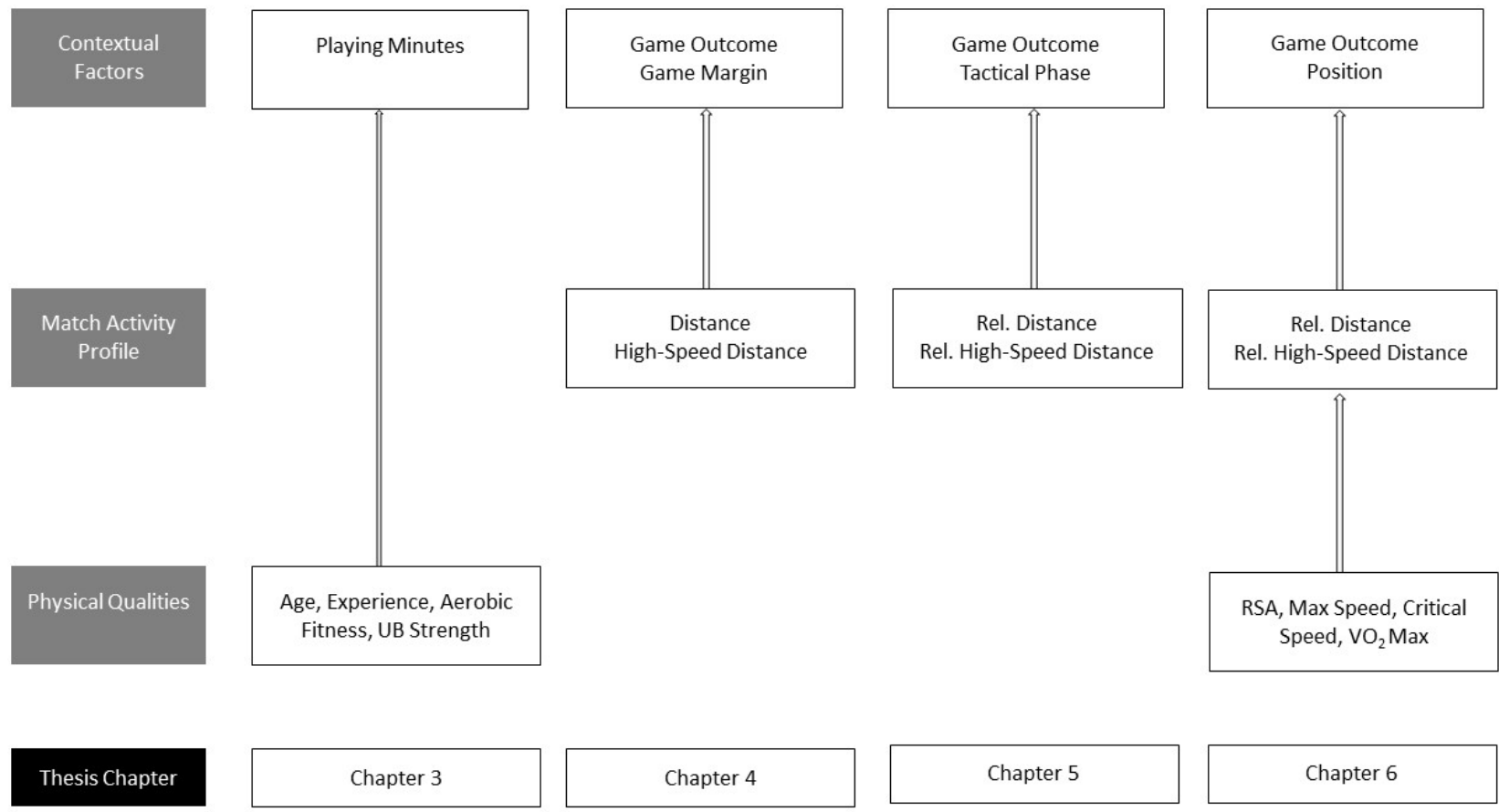


Figure 7.1. The interaction between physical qualities, match activity profiles and contextual factors in international women's Rugby Sevens.

UB = upper=body, RSA = repeated-sprint ability, $\dot{V}O_{2max}$ = maximal aerobic power

7.3 Points of Difference

This program of research advances the existing understanding in international women's Rugby Sevens. It provides an overview of the elite player and how player physical qualities and in-game demands interact at the highest level on women's contact team sport (Figure 7.1).

The points of difference made by this program of research are:

- (i) The women's game of Rugby Sevens is uniquely different from the men's game; research on males is not applicable to female athletes; a notion which has now been extended via exploring relationships among physical qualities, game activity profiles and key contextual influences.
- (ii) The women's game of Rugby Sevens requires a robust athlete who possesses well-developed upper-body strength, aerobic fitness, critical speed, maximum running velocity and repeated-sprint ability. These physical qualities can now be extended into relation to playing selection, game outcomes, and playing position.
- (iii) Rugby Sevens is both a metabolically and physically demanding sport. Physiological and activity profiles change with selected contextual factors such as game half, game outcome and playing position. Relative running intensities and relative high-speed running intensities are closely related to a large range of game contextual factors.
- (iv) Differences exist in the physical demands of defense and attack and between tactical play in wins and losses. Defense is relatively more demanding than attack independent of outcome and winning attacking tactical play has greater relative high-speed demands than losing play.

- (v) The interpretation of in-game demands can vary depending on how in-game data is coded. Relative intensities increase with the inclusion of only ball-in-play time into game demand analysis. In-game intensities can be underestimated by over 50% if ball-out-of-play cycles are included in the analysis.
- (vi) Women's Rugby Sevens players who are older, more experienced, and supported by a professional training environment play more minutes at the elite level.

7.4 Strengths

The strengths of this program of research are summarized as:

- (i) Access to a single group of elite athletes over a prolonged period of time provided rigour of investigation through:
 - a. high levels of compliance
 - i. 24 professional women's Rugby Sevens players, completing 8-12 training sessions across 4-6 days a week, with less than 10% of sessions missed due to injury, illness or family matters
 - b. homogeneity of training and competitive exposure
 - c. on-going and reliable approaches to data collection
 - d. the integration of data from across a multitude of physiological, analytical, medical, strength and conditioning, biomechanical and tactical domains
- (ii) Ability to sample and analyse data not only on an elite athlete population, but within a squad of players who were consistently ranked among the perennial top three international competitive nations.

- (iii) Captured longitudinal data on an emerging women's contact team sport in its first Olympic Games quadrennial.
- (iv) Guided applied and relevant evidence to support best practice in sport science support for athletes in the targeted training group.
- (v) Adds to the body of literature in elite women's Rugby Sevens and elite women's team sport in general.

7.5 Limitations

The limitations of this program of research are summarized as:

- (i) The relatively small sample size of a homogenous group of elite athletes could be seen as limitation to this program of research. Due to the definition of "elite", there will be very few athletes who fit this definition. Due to the elite nature of high performance sport, national team training groups are by nature smaller in size. The training group who was targeted in this thesis ranged from 22 to 26 athletes on a yearly basis. All athletes in this group were selected by the national coaching squad and as such would be considered elite representatives of a women's Rugby Sevens population. Athletes lower on the developmental pathway were not included in this training group and were therefore not targeted as part of this series of studies. It is likely that certain differences in physical qualities (lower-body strength) and in-game demands (positional groups) would be more pronounced if a sub-elite population was also sampled allowing for comparison to the elite group.
- (ii) Women's Rugby Sevens has only recently emerged as an Olympic sport and is in the early stages of professionalization. Due to this, changes in the winning style of play

evolved rapidly as the technical and tactical ability of athletes improved concurrently with their physical development. It is important to note that as the sport remains within relative early phase of evolution compared with other female team sports. At this stage, athletes are able to participate at a high level if they simply possess either high skill or unique physical abilities. As the sport continues to grow this will become less of the norm and more of the exception. Specifically, it is postulated that to continue to be successful long-term athletes, players will require both a combination of skill and physical abilities. This rapid evolution of the game requires consideration when interpreting data and findings from earlier projects.

(iii) When compared with the other top teams in the world, the team studied had a defensive focus style of play. The team's attack was still proficient compared with over 80% of the teams playing at the top level on women's Rugby Sevens. However, when compared with the other world leading teams, the team's attack would be considered the weakest. This defensive playing style was successful across the 4 years of the study with the team having a 71% winning percentage, scoring 3100 points while only conceding 1490. It is possible that a team with a more dominant attacking style may aspire for different physical qualities in their athletes and also see subtly different activity and physiological profiles during competitive play. Nonetheless, a framework for investigation has now been presented on which future studies can build.

(iv) A further limitation of this study lies in the reliability of the microtechnology system used. Internal pilot work examining the reliability of the systems measures of accelerations, deceleration and contact did not yield acceptable coefficients of variation. In further internal examinations, the data from the microtechnology were in poor agreement

with data generated by the team's video analyst on contact and tackle incidents. The current imprecision of available microtechnology may have therefore resulted in an under-representation of both the contact and acceleration and deceleration elements of the women's game of Rugby Sevens in this series of studies.

7.6 Future Directions

The work on international women's Rugby Sevens in this thesis has helped to establish a foundation of knowledge on the physical qualities of the athletes involved in the game and how these qualities interact with the specific demands of the game. Due to the paucity of research, both in women's Rugby Sevens and women's team sport in general, a number of future directions for applied research still exist:

- (i) With the continued evolution of the women's game as a result of professionalization of the training and athletes, further changes future changes can be expected in the specific demands of the game and the physical qualities of the athletes. Tracking both the changes in the game demands as well as the longitudinal changes in player physical qualities across the coming Olympic cycle and throughout the developmental pathway will help coaches and practitioners understand the rate of improvement in the game and athletes on a year-to-year basis allowing for informed training decisions to be made.
- (ii) With the groundwork provided across the series of studies in this thesis further examination into the relationship of tactical execution, technical abilities, game demands, and physical qualities can now be conducted. These types of studies will generate a clearer

understanding of how to develop a women's Rugby Sevens player who is more physically robust, skillful, and tactically aware.

(iii) Exploring the relationship between specific game moments leading to either successful or unsuccessful attacking or defensive play and the preceding physical demands would help coaches and practitioners to understand the effect of activity and physiological demands on in-game decision making. This understanding would support training prescription, helping prepare players to better execute in-game tactics resulting in successful game moments.

(iv) With the studies conducted over the past few years on the women's game of Rugby Sevens a better understanding exists of the in-game demands and their relationship to contextual factors and player physical qualities. Further research is now required to identify the worst-case scenario found in international women's Rugby Sevens. To support this, exploring other methods of quantifying peak work rates and demands, such as rolling time frames, may be needed to further understand the specific in-game demands and how these will change with respect to contextual factors in relation not only to game demands but the athlete's fitness levels, tactical execution and level of skill.

(v) As shown in this thesis, relative high-speed running and repeated-sprint ability are key physical qualities that should be developed in female Rugby Sevens athletes. Further examination into repeated-sprint ability, repeat-effort ability and the relation of these qualities to in-game worst case scenarios is required.

(vi) Individualization of game activity metrics and an understanding of how game and tournament activity profiles change specific to an athlete's individual physical qualities such as: speed, strength, and both anaerobic and aerobic fitness could lead to better specific

programming for these athletes, helping to better select teams, manage in-game fatigue and reduce player injury rates.

(vii) Further examination into the relationship between game activity and physiological variables is warranted. Given that no single biological system exists in isolation, understanding the interaction between variables used to quantify activity and physiological demands is needed. This work would help to better understand the nature of in-game play and how the interaction of accelerations, decelerations, sprints, and contacts affect energy system demands and fatigue throughout the course of a game.

(viii) Due to the limited body of research that existed on women's Rugby Sevens only a few years ago, the majority of studies on women's Rugby Sevens had focused on better understanding the game and the athlete across relatively shorter time frames. Limited research has been performed on chronic loading of athletes examining the interaction of training loads, adaptation, peaking and injury. Studies of this type are needed to better inform long-term decision-making around the athlete and to support training for both performance and resilience.

7.7 Practical Applications

The findings presented in this thesis will help to guide training and talent identification processes in women's Rugby Sevens throughout the athlete pathway. Results from the thesis have helped to identify key physical qualities that support performance while also characterizing the game demands present in women's Rugby Sevens. With this foundational knowledge coaches, sport scientists and strength and conditioning coaches will now have evidence upon which to inform

training decisions. This in turn will support the development of more robust and dominant women's Rugby Sevens players.

Physical qualities that were identified as important for women's Rugby Sevens players include: upper-body strength, aerobic fitness, critical speed, repeated-sprint ability and maximal running velocity. It is recommended that practitioners working in women's Rugby Sevens endeavour to develop an integrated training approach that develops these specific physical qualities and also the properties known to underpin these qualities. This preparation strategy should address the development of these physical qualities in both a general and specific fashion. The purpose of such a strategy would be to develop players who are resilient to the training load required for elite performance and to build players who are physically superior to their opposition. Developing the physical qualities listed above, along with providing athletes time to develop in a professional training environment, will help to establish the long term success of both the athlete and program.

The elite game of women's Rugby Sevens is demanding from both a physical and physiological standpoint. Absolute and relative high-speed running are important in-game variables related to a number of contextual factors in women's Rugby Sevens. Running hard and consistently throughout a game supports successful tactical play that influences game outcomes. Being able to run at high-speeds and maintain this ability throughout the course of a game and tournament is therefore important for team success. It is not only important to develop the key physical qualities that underpin high-speed running ability in women's Rugby Sevens players but to also expose athletes to game-specific scenarios in training to help these players develop this ability within the specific contextual framework of the game. Designing training such that players have been

prepared to experience worst case in-game scenarios will help to inoculate players to this stress when experienced in competition.

7.8 Conclusions

With the recent emergence of women's Rugby Sevens on the international stage a paucity of research existed. This thesis advances the body of knowledge in women's Rugby Sevens and helps to characterize both the game and athlete in this unique fast-paced sport. As research on women in elite team sport is scarce, this thesis also adds to the greater body of knowledge in women's elite sport and further supports female-specific training prescription.

To meet the in-game demands of women's Rugby Sevens, the female player is required to be strong and fast, as well as anaerobically and aerobically fit. Understanding how to develop a robust female Rugby Sevens player will not only better prepare the athlete for the game but also support successful game-play that is dynamic and exciting. Improved well-founded training prescription will help to support further evolution of the women's game of Rugby Sevens, improving its opportunity for exposure and supporting the growth of the game. This exposure and growth will provide more opportunities for young women to experience and participate in the game, further leading to its growth and advancement.

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Appendices

Appendix A - Evidence of Publications

Chapter 3 – Goodale TL, Gabbett TJ, Stellingwerff T, Tsai MC, Sheppard JM. Relationship between physical qualities and minutes played in international women's Rugby Sevens. *International Journal Sports Physiology Performance*. 2016, 11(4), 489-494.

International Journal of Sports Physiology and Performance, 2016, 11, 489-494
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Human Kinetics 
ORIGINAL INVESTIGATION

Relationship Between Physical Qualities and Minutes Played in International Women's Rugby Sevens

Tyler L. Goodale, Tim J. Gabbett, Trent Stellingwerff, Ming-Chang Tsai, and Jeremy M. Sheppard

Purpose: To investigate the physical qualities that differentiate playing minutes in international-level women's rugby sevens players. **Methods:** Twenty-four national-level female rugby sevens players underwent measurements of anthropometry, acceleration, speed, lower- and upper-body strength, lower-body power, and aerobic fitness. Playing minutes in international competition were used to differentiate players into 2 groups, a high- or low-playing-minutes group. Playing minutes were related to team selection, which was determined by the coaching staff. Playing minutes were therefore used to differentiate performance levels. **Results:** Players in the high-playing-minutes group (≥ 70 min) were older (mean \pm SD 24.3 ± 3.1 vs 21.2 ± 4.3 y, $P = .05$, effect size [ES] = 0.77 ± 0.66 , 90% confidence limit) and had greater experience in a national-training-center environment (2.4 ± 0.8 vs 1.7 ± 0.9 y, $P = .03$, ES = 0.83 ± 0.65), faster 1600-m time (374.5 ± 20.4 vs 393.5 ± 29.8 s, $P = .09$, ES = -0.70 ± 0.68), and greater 1-repetition-maximum upper-body strength (bench press 68.4 ± 6.3 vs 62.2 ± 8.1 kg, $P = .07$, ES = 0.80 ± 0.70 , and neutral-grip pull-up 84.0 ± 8.2 vs 79.1 ± 5.4 kg, $P = .12$, ES = 0.68 ± 0.72) than athletes who played fewer minutes. Age ($r_s = .59 \pm .28$), training experience ($r_s = .57 \pm .29$), bench press ($r = .44 \pm .36$), and 1600-m time ($r = -.43 \pm .34$) were significantly associated with playing minutes. Neutral-grip pull-up and bench press contributed significantly to a discriminant analysis. The average squared canonical correlation was .46. The discriminant analysis predicted 7 of 9 and 6 of 10 high- and low-playing-minutes athletes, respectively. **Conclusions:** Age, training experience, upper-body strength, and aerobic fitness differentiated athlete playing minutes in international women's rugby sevens.

Keywords: speed, strength, aerobic fitness, playing minutes

Rugby sevens is growing in popularity, with its recent inclusion in the 2016 Olympic Games. Rugby sevens is a variation of 15-player rugby union, with the main difference being 7-minute halves separated by a 2-minute halftime in rugby sevens versus an 80-minute game in rugby union. The game is normally played tournament style with 2 or 3 games per day over 2 or 3 days.

Rugby sevens is characterized by high physical demands relative to minutes of play.¹⁻³ Running velocities, distances covered, numbers of accelerations, and work-to-rest ratios are greater than in other forms of rugby (union and league).^{4,5} These findings suggest that training and physical preparation should be specific to rugby sevens athletes. Most international programs consist of rugby sevens specialist players, and this trend will continue as the game further evolves.

While the demands of rugby sevens have been documented,^{1,3,6} limited data exist on the physical characteristics of rugby sevens players.⁶⁻⁹ Unlike the large body of work performed in other field sports,¹⁰⁻¹⁴ only 1 study has investigated the differences between rugby sevens players of different playing standards,⁹ and none have involved international-level female players.

In rugby league,¹⁴⁻¹⁶ age, stature, mass, lean-mass ratio, speed, change-of-direction speed, high-intensity-running ability, lower-body power, and aerobic fitness are related to a player's on-field

performance and discriminate performers of varying playing levels.¹⁴⁻¹⁷ In addition, sprinting momentum, absolute upper-body strength, and strength-endurance qualities differentiated player rank.^{13,18} In Australian rules football, age, speed, lower-body power, repeated-sprint ability, and high-intensity-running ability differentiate starters from nonstarters.^{10,13} While these studies provide important information on the relationship between physical qualities, performance, playing rank, and team selection in contact field sport, to date no research has identified the relationships between physical qualities and team selection in female rugby sevens players.

Of the research that has been performed on international women's rugby sevens,^{1,3,19} no study has characterized the physical capacities of international-level female rugby sevens players in relation to playing minutes. Therefore, the purpose of this study was to examine which, if any, physical qualities differentiate playing minutes in international women's rugby sevens players.

Methods

Experimental Design

A cross-sectional design was used to assess physical characteristics and their relationship to playing minutes in international women's rugby sevens players. Players were tested for anthropometry, acceleration, speed, lower- and upper-body strength, lower-body power, and aerobic fitness over a 3-day period on 3 or 4 occasions during the general preparatory and competitive phases of the 2013-14 world rugby women's sevens series training cycle. Players performed the physical assessments as part of their inclusion in the National Training Centre (NTC) program. Testing was performed based on the annual international competition demands. Unless a medical

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Chapter 4 – Goodale TL, Gabbett TJ, Tsai MC, Stellingwerff T, Sheppard JM. The effect of contextual factors on physiological and activity profiles in international women’s Rugby Sevens. *International Journal Sports Physiology Performance*. 2017, 12(3), 370-376.

International Journal of Sports Physiology and Performance, 2017, 12, 370-376
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ORIGINAL INVESTIGATION

The Effect of Contextual Factors on Physiological and Activity Profiles in International Women’s Rugby Sevens

Tyler L. Goodale, Tim J. Gabbett, Ming-Chang Tsai, Trent Stellingwerff, and Jeremy Sheppard

Purpose: To evaluate the effects of contextual game factors on activity and physiological profiles of international-level women’s rugby sevens players. **Methods:** Twenty international-level female rugby sevens players from the same national team participated in this study. Global positioning system and heart-rate data were collected at 5 World Rugby Women’s Sevens Series events (2013–14 season). **Results:** Total, moderate-speed (0.2–3.5 m/s), and high-speed running (3.5–5.0 m/s) distances were significantly greater in the first half ($20.1\% \pm 4.1\%$, $17.6\% \pm 6.9\%$, $24.5\% \pm 7.8\%$), during losses ($11.4\% \pm 6.1\%$, $6.1\% \pm 6.4\%$, $26.9\% \pm 9.8\%$), during losses of large magnitudes (≥ 2 tries) ($12.9\% \pm 8.8\%$, $6.8\% \pm 10.0\%$, $31.2\% \pm 14.9\%$), and against top-4 opponents ($12.6\% \pm 8.7\%$, $11.3\% \pm 8.5\%$, $15.5\% \pm 13.9\%$). In addition, total distance increased ($5.0\% \pm 5.5\%$) significantly from day 1 to day 2 of tournaments, and very-high-speed (5.0–6.5 m/s) running distance increased significantly ($26.0\% \pm 14.2\%$) during losses. Time spent between 90% and 100% of maximum heart rate ($16.4\% \pm 14.5\%$) and player load ($19.0\% \pm 5.1\%$) were significantly greater in the second half. No significant differences in physiological or activity profiles were observed between forwards and backs. **Conclusions:** Game half, game outcome, tournament day, opponent rank, and margin of outcome all affected activity profiles, whereas game half affected physiological profiles. No differences in activity or physiological profiles were found between playing positions. Practitioners are advised to develop high-speed running ability in women’s rugby sevens players to prepare them to tolerate the varying factors that affect activity profiles.

Keywords: microtechnology, GPS, game outcome, high-speed running, heart rate, female athletes

With its recent inclusion in the 2016 Olympic Games, rugby sevens is rapidly growing in popularity. It is a high-intensity, intermittent collision sport^{1,2} and is a variation of 15-player rugby union. Both the laws and field size of the 2 games are similar but there are fewer players per side in the game of rugby sevens and games are shorter (14 vs 80 min) in duration. Rugby sevens is played in a tournament structure with 2 or 3 games played per day over 2 to 3 days.

Recent research^{3–6} has examined both the activity and physiological profiles of rugby sevens for both male and female players, with the majority of this research examining the men’s game.^{4,5,7–13} Rugby sevens has higher physical demands relative to minutes of play than in other forms of rugby (union and league) with relative distances of 85 to 120 m/min covered and work-to-rest ratios of 1.0:0.5.^{3,10} In the women’s game, players cover total distances between 1150 to 1800 m, with relative demands between 75 to 115 m/min in just 14 minutes of play. Approximately 10% to 20% of the game is spent at high running speeds (≥ 5 m/s) with 30% to 50% of that distance spent at top speed (≥ 5.6 m/s).^{5,6,12,13} Average sprint distance between 15 and 22 m with maximum sprints of ~ 55 m in length and top speeds ranging from 6.8 to 7.9 m/s have also been observed.^{5,6,13} Approximately 75% to 85% of the game is played at heart rates (HRs) $> 80\%$ of maximum, with approximately a quarter of the game spent between 80% and 90% of maximum HR (HR_{max}) and more than half the game spent above 90% of HR_{max}.^{5,6}

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The majority of research performed on women’s sevens has examined domestic or national competitions such as continental championships or invitation tournaments.^{5,6,13} To date, only 1 study has examined game activity profiles of the top tier competition in the women’s game.¹² A higher level of women’s competition has been shown to be associated with both greater absolute and relative game demands. Female players competing in international level competitions travel 17% greater total and relative distances in games. Average speed (+15%), peak speed (+12%), number of sprints (+75%), distance at top speed (+50%), and the distance covered in the highest speed bands (+40%) are all greater in higher level competitions.⁶ Players of higher standard also perform a greater number of high-intensity accelerations and decelerations.^{6,13} Physiological demands are also greater in international competition, characterized by 34% greater total time above 90% HR_{max}.⁶

Activity and physiological profiles vary with respect to a number of contextual game factors such as physical characteristics of the athletes, positional group, opponent rank, score line, tournament day, game half, athlete rank, athlete playing time, and game outcome.^{1,8,10,12–15} In men’s rugby sevens, contextual factors have been found to affect running activity variables such as peak distance, relative distance, high-speed running distance, and number of accelerations per minute of play.¹⁴ To date, no research, to our knowledge, has been conducted on the effect of contextual factors on international women’s rugby sevens. It is important to have an understanding of top international-level competition and how the in-game profile changes with respect to game contextual factors. This information will not only inform training management of elite athletes but will support athletes in the developmental pathway of rugby sevens.

The aim of this study was to evaluate the activity and physiological profiles of international-level women’s rugby sevens.

Appendix B - Information Letters and Consent Forms

INFORMATION LETTER TO PARTICIPANTS

TITLE OF PROJECT: Relationship between physical qualities and activity profiles of elite women's sevens players

PRINCIPAL SUPERVISOR: Dr. Tim Gabbett

CANADIAN SPORTS INSTUTE (CSI) EMPLOYEE & STUDENT RESEARCHER: Tyler Goodale
PROGRAM IN WHICH ENROLLED: Doctor of Philosophy

Dear Participant,

You are invited to participate in a study investigating the relationship between physical qualities and activity profiles in elite women's sevens. The knowledge gained from this study will help coaches and sport scientists plan training more effectively in order to help athletes better prepare for the specific demands of the sevens game. In addition, this study will help contribute to the larger body of knowledge with respect to elite women's sport. You have been approached to participate in this study because you are a member of the Canadian National Senior Women's Sevens Training Centre (CNSWSTC).

The possible risks, inconvenience and/or discomfort to you are negligible and are not outside of normal participation at the elite level of sevens rugby.

As a member of CNSWSTC you will be asked to complete the following physical tests; one repetition maximum power clean, front squat, bench press, and neutral grip pull up, broad jump, triple broad jump, 40m sprint, 1600 m time trial, general anthropometry and skinfold body composition. You will also be asked to wear a small GPS unit during training and at each international competition attended by the National Senior Women's Sevens team. GPS units are widely used at all international rugby sevens competitions; they provide information on player movements (e.g. distance covered, tackles etc.) throughout the match. Your time commitments will not be outside of what is normally asked of you as a member of the CNSWSTC.

The findings of this research will help your coaches and sport scientist improve your training and preparation for international competition by helping them to gain a better understanding of the physical demands of women's international rugby sevens and which physical characteristics best relate to performance. It is our intention to present the findings of the group data in the form of a journal publication. This means other athletes within the community will be able to benefit from the knowledge gained from this study. Please note that you will not be named within this report and no one other than the team of researchers will be able to identify your results at any time during or following the testing. An identification number will be assigned to your data, known only to the researchers. Please be advised that the student researcher in this project, Tyler Goodale, along with being a PhD student enrolled at Australian Catholic University (ACU) is also an employee of the CSI.

Be advised that as a participant you are free to refuse consent altogether without having to justify that decision, and if you wish to, can withdraw consent and discontinue participation in the study at any time without giving a reason. Withdrawal from the research study will not impact upon your team selection.

Should you have any questions regarding this project, please use the following contacts

Principal Investigator:

Dr. Tim Gabbett
+617 3623 7589
tim.gabbett@acu.edu.au

CSI Employee & Student Researcher:

Tyler Goodale
250 413 7524
tgoodale@csipacific.ca

School of Exercise Science
ACU National, McAuley Campus, 1100 Nudgee Road, Banyo, QLD, 4014

On completion of the study, we would be delighted to discuss with you the findings of the study, and your individual results.

Before deciding to take part in this study, it is important for you to be aware that this study has gained approval by the Human Research Ethics Committee at Australian Catholic University. This vigorous process ensures that the study is worthwhile and protects you the participant.

In the event that you have any complaint or concern about the way you have been treated during the study, or if you have any query that the Investigators have not been able to satisfy, you may write to the Research Ethics Manager care of the Office of the Deputy Vice-Chancellor (Research).

Research Ethics Manager (ResEthics.Manager@acu.edu.au)

Office of the Deputy Vice-Chancellor (Research)

Australian Catholic University

North Sydney Campus

PO Box 968

North Sydney, NSW 2059

Any complaint or concern will be treated in confidence and fully investigated. The participant will be informed of the outcome.

If you agree to participate in this project, you should sign both copies of the Consent Form. Please retain one copy for your records and return the other copy to the Principal Investigator.



Tim Gabbett
Principal Investigator



Tyler Goodale
Student Researcher

CONSENT FORM
Copy for Researcher/Participant

TITLE OF PROJECT: Relationship between physical qualities and activity profiles of elite women's sevens players.

PRINCIPAL INVESTIGATOR: Dr. Tim Gabbett

CANADIAN SPORT INSTITUTE (CSI) EMPLOYEE & STUDENT RESEARCHER: Tyler Goodale
PROGRAM IN WHICH ENROLLED: Doctor of Philosophy

I (*the participant*) have read (*or, where appropriate, have had read to me*) and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree to participate in this study, which involves assessing the physical requirements and demands of competition in rugby sevens. Physical requirements will be evaluated via strength (1RM bench press, pull up, front squat, power clean), jump (broad and triple broad jump), sprint (40m) and aerobic fitness (1600m) tests. Game demands will be assessed via GPS and HR data collected during competition.

Realising that I can withdraw my consent at any time, without comment or penalty or affect upon my future relationship with the researchers or the team, I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify me in any way. I have also been made aware that the student researcher for this project is also an employee of the CSI.

NAME OF PARTICIPANT:.....

SIGNATURE: DATE:.....

NAME OF PRINCIPAL INVESTIGATOR:

SIGNATURE: DATE:.....

Appendix C – Ethics Approval

From: Kylie Pashley [mailto:Kylie.Pashley@acu.edu.au] On Behalf Of Res Ethics
Sent: June-09-14 7:39 PM
To: Tim Gabbett; Tyler Goodale; Tyler Goodale
Cc: Res Ethics
Subject: 2014 108Q Ethics application approved!

Dear Applicant,

Principal Investigator: Dr Timothy Gabbett Student Researcher: Mr Tyler Goodale Ethics Register Number: 2014 108Q Project Title: Relationship Between Physical Qualities and Activity Profiles of Elite Women's Sevens Players Risk Level: Low Risk Date Approved: 10/06/2014 Ethics Clearance End Date: 31/01/2017

This email is to advise that your application has been reviewed by the Australian Catholic University's Human Research Ethics Committee and confirmed as meeting the requirements of the National Statement on Ethical Conduct in Human Research.

This project has been awarded ethical clearance until 31/01/2017. In order to comply with the National Statement on Ethical Conduct in Human Research, progress reports are to be submitted on an annual basis. If an extension of time is required researchers must submit a progress report.

Whilst the data collection of your project has received ethical clearance, the decision and authority to commence may be dependent on factors beyond the remit of the ethics review process. The Chief Investigator is responsible for ensuring that appropriate permission letters are obtained, if relevant, and a copy forwarded to ACU HREC before any data collection can occur at the specified organisation. Failure to provide permission letters to ACU HREC before data collection commences is in breach of the National Statement on Ethical Conduct in Human Research and the Australian Code for the Responsible Conduct of Research. Further, this approval is only valid as long as approved procedures are followed.

If you require a formal approval certificate, please respond via reply email and one will be issued.

Decisions related to low risk ethical review are subject to ratification at the next available Committee meeting. You will be contacted should the Committee raises any additional questions or concerns.

Researchers who fail to submit a progress report may have their ethical clearance revoked and/or the ethical clearances of other projects suspended. When your project has been completed please complete and submit a progress/final report form and advise us by email at your earliest convenience. The information researchers provide on the security of records, compliance with approval consent procedures and documentation and responses to special conditions is reported to the NHMRC on an annual basis. In accordance with NHMRC the ACU HREC may undertake annual audits of any projects considered to be of more than low risk.

It is the Principal Investigators / Supervisors responsibility to ensure that:

1. All serious and unexpected adverse events should be reported to the HREC with 72 hours.
2. Any changes to the protocol must be approved by the HREC by submitting a Modification Form prior to the research commencing or continuing.
3. All research participants are to be provided with a Participant Information Letter and consent form, unless otherwise agreed by the Committee.

For progress and/or final reports, please complete and submit a Progress / Final Report form:

http://www.acu.edu.au/research/support_for_researchers/human_ethics/forms

For modifications to your project, please complete and submit a Modification form:

http://www.acu.edu.au/research/support_for_researchers/human_ethics/forms

Researchers must immediately report to HREC any matter that might affect the ethical acceptability of the protocol eg: changes to protocols or unforeseen circumstances or adverse effects on participants.

Please do not hesitate to contact the office if you have any queries.

Kind regards,

Kylie Pashley

on behalf of ACU HREC Chair, Dr Nadia Crittenden

Ethics Officer | Research Services

Office of the Deputy Vice Chancellor (Research) Australian Catholic University