Maximising Performance in Female Rugby Sevens Athletes

A Thesis

submitted in fulfilment

of the requirements for the degree

of

Doctor of Philosophy in Health, Sport, and Human Performance

at

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by

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Abstract

Rugby Sevens is a field-based team sport contested by two teams of seven players over two 7-minute halves. Rugby Sevens matches are played in a tournament format with teams playing five to six matches over two to three days. Since the inclusion of Rugby Sevens in the Olympic Games, there has been a growing public and scientific interest in this game worldwide. Most studies to date in Rugby Sevens have been conducted with men, with limited research involving women. Therefore, this Thesis aimed to expand the body of knowledge relative to the women's Rugby Sevens game, with a specific focus on how to maximise performance.

Chapter 2 reviewed the existing female Rugby Sevens studies addressing the match demands (match running and physiological demands), anthropometric characteristics, and physical qualities. The review also highlighted the differences between competition levels and playing positions identified in the scientific literature. The existing research indicates greater running demands and intensities, but lower physiological responses in international than national matches. During international matches, backs demonstrated greater running demands, running intensities, and physiological responses than forwards. Overall, elite athletes were characterised by superior physical qualities compared with nonelite athletes. Furthermore, at the elite level, specific physical qualities differentiated forwards from backs.

The literature review indicated that possessing well developed physical qualities could be beneficial for on-field performance in women's Rugby Sevens. In Chapter 3, the association between physical-test measures with various match-running and match-action measures was evaluated in 30 women's Rugby Sevens players representing five different New Zealand

Provincial Union teams. There was good evidence of positive effects of many physical-test measures on match high-intensity running. Furthermore, there was some evidence of positive effects of speed and running fitness on match total running and high intensity changes in speed, and of negative effects of maximal strength and jump height on match total running and high intensity changes in speed. There were fewer substantial associations between physical-test measures and match actions, but there was good evidence of positive effects of squat and jump height on tries scored suggesting that enhancing players' jump height and back-squat performance could increase the likelihood of match success in women's Rugby Sevens.

In Chapter 4, the effectiveness of two running fitness programmes on the locomotor profile of eight professional female Rugby Sevens players was investigated. Six sessions of short-interval high-intensity interval training (HIIT) led to possible improvements in maximal aerobic speed. In contrast, six sessions of long-interval HIIT had a possible negative effect on maximal aerobic speed. There were small positive changes in maximal sprinting speed following both programmes and small positive changes in the anaerobic speed reserve following the long-interval programme; however, all these changes were unclear and suggest a greater sample size is needed to get more evidence about the magnitude of these changes.

Female physiology is unique and largely influenced by the menstrual cycle. The cyclic fluctuations of endogenous sex hormones across the menstrual cycle could have implications on sport performance; however, limited research exists on this topic. Therefore, in Chapter 5, the potential effects of menstrual phase on athletic performance in four nonelite Rugby players were investigated. At a group-level, possibly greater performances were observed in the countermovement jump, drop jump, and isometric mid-thigh pull in the late luteal phase compared with the menstruation, luteal, and follicular to ovulation phases. However, large variations in responses were observed at an individual-level, suggesting that accounting for individual responses during the menstrual cycle will likely be beneficial to training prescription and interpreting performance monitoring results. Overall, this Thesis expands the literature pertaining to the women's Rugby Sevens game and adds new knowledge to practitioners looking to maximise their athletes' performance.

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Acknowledgements

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List of abbreviations

Δ%: Percent difference

1RM: 1-repetition maximum

30-15 IFT: 30-15 Intermittent Fitness Test

ASR: Anaerobic speed reserve

ATP: Adenosine triphosphate

B: Backs

CI: Confidence interval

CL: Confidence limits

CMJ: Countermovement jump

CV: Coefficient of variation

DALDA: The Daily Analysis of Life Demands for Athletes questionnaire

DJ: Drop jump

ES: Effect size

F: Forwards

GEE: Generalised estimating equations

GPS: Global positioning system

HIIT: High-intensity interval training

HR: Heart rate

I: International

ICC: Intraclass correlation coefficient

IMTP: Isometric mid-thigh pull

MAS: Maximal aerobic speed

Max: Maximal

MSRT: Multistage Shuttle Run Test

MSS: Maximal sprinting speed

N: National

NA: Not applicable

OR: Odds ratio

PF: Peak force

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

RPE: Rate of perceived exertion

RSR: Reactive strength ratio

SD: Standard deviation

SE: Standard error

SF: Skinfolds

SWC: Smallest worthwhile change

TE: Typical error

USG: Urine specific gravity

VJ: Vertical jump

WS: World Series

Yo-Yo IR1: Yo-Yo Intermittent Recovery Test Level 1

Peer-reviewed publications arising from this Thesis

Published and submitted manuscripts presented in the Thesis:

Chapter 2

Sella FS, McMaster DT, Beaven CM, Gill ND, Hébert-Losier K. Match demands, anthropometric characteristics, and physical qualities of female Rugby Sevens athletes: A systematic review, *Journal of Strength and Conditioning Research*, 33 (12), 3463-3474, 2019.

Chapter 3

Sella FS, Hopkins WG, Beaven CM, McMaster DT, Gill ND, Hébert-Losier K. The associations between physical-test performance and match performance in women's Rugby Sevens players, *Biology of Sport*, 40 (3), 775-785, 2023.

Chapter 5

Sella FS, Beaven CM, Sims ST, McMaster DT, Gill ND, Hébert-Losier K. The effects of menstrual cycle phase on physical performance in female Rugby athletes: A case-study, *The Journal of Sport and Exercise Science*, 5 (5), 310-320, 2021.

Appendix

Sella FS, Hébert-Losier K, Beaven CM, McMaster DT, Harvey M, Gill ND. Performance in the 1.2 km shuttle run test reflects fitness capacities in Rugby players, *The Journal of Australian Strength and Conditioning*, 29 (5), 7-14, 2021.

Peer-reviewed conference presentations arising from the Thesis

Sella FS, Beaven CM, Sims ST, McMaster DT, Gill ND, Hébert-Losier K. The effects of menstrual cycle phase on physical performance in female Rugby athletes: A case series study. *Sport and Exercise Science New Zealand Conference*, Palmerston North, New Zealand, November 2019 (Oral presentation).

Sella FS, Hébert-Losier K, McMaster DT, Harvey M, Gill ND, Beaven CM. Performance in the 1.2 km shuttle run test reflects fitness capacities in Rugby players. *Sport and Exercise Science New Zealand Conference*, Christchurch, New Zealand, November 2020 (Poster presentation).

Sella FS, Hébert-Losier K, Gill ND, McMaster DT, Beaven CM. Low-volume high-intensity interval training programmes in female Rugby Sevens players: A pilot study. *Sport and Exercise Science New Zealand Conference*, Auckland, New Zealand, November 2022 (Poster presentation).

Chapter 1 – Introduction

Introduction and rationale of the Thesis

Rugby Sevens is an intermittent, field-based sport characterised by high-intensity activities and collisions (Ross et al., 2014). Rugby Sevens is a variation of Rugby Union and consists of two teams of seven players competing over two 7-minute halves separated by a 2-minute halftime, as opposed to 15 players playing two 40-minute halves separated by 10–15 minutes in Rugby Union. Rugby Sevens matches are played in a tournament format with teams contesting five to six matches over two to three days. The top National teams in the world compete annually in the Men's and Women's Sevens World Series, which are comprised of ten and six and international tournaments, respectively.

Since the decision in 2009 to include Rugby Sevens in the Olympic Games beginning in 2016, the popularity of this sport has increased worldwide, and several countries have established professional full-time Rugby Sevens programmes. The growing interest in Rugby Sevens has also stimulated an increase in the number of publications addressing various aspects of the game (Figure 1). Most of these studies have been conducted on male Rugby Sevens athletes, whereas there has been limited research specific to female Rugby Sevens. Given the differences observed between male and female Sevens athletes in anthropometric characteristics (Clarke et al., 2017b), physical qualities (Clarke et al., 2017b), match running (Clarke et al., 2017b), and match actions associated with success (Barkell et al., 2016), the findings from men's research might not be applicable to the women's game. The need for research specific to female Sevens athletes is further highlighted by the well-known physiological differences between sexes (Emmonds et al., 2019).

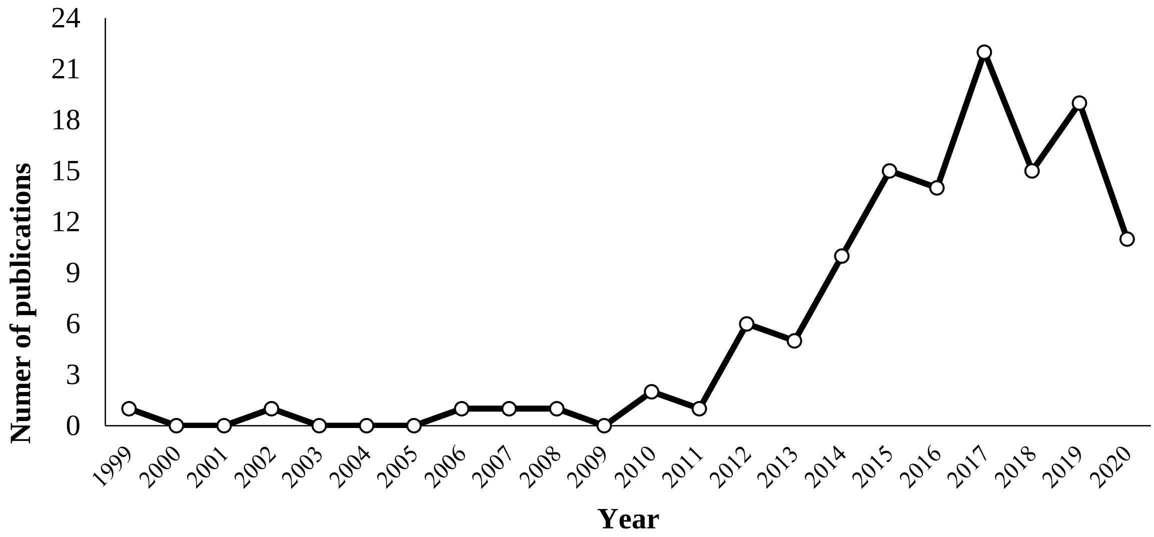

Figure 1. The number of Rugby Sevens publications from the earliest records (1999) to the year 2020 sourced from PubMed

Most of the existing female Rugby Sevens literature has described players' physical qualities (Agar-Newman et al., 2017; Clarke et al., 2017b; Goodale et al., 2016; Leite et al., 2016; Ohya et al., 2015; Vescovi & Goodale, 2015) and the match running demands in different competitions (Clarke et al., 2015a; Clarke et al., 2017b; Goodale et al., 2017; Malone et al., 2020; Misseldine et al., 2021; Portillo et al., 2014; Reyneke et al., 2018; Suarez-Arrones et al., 2012; Vescovi & Goodale, 2015), with some of these studies also assessing players' physiological responses to matches (i.e., heart rate values) (Goodale et al., 2017; Malone et al., 2020; Portillo et al., 2014; Suarez-Arrones et al., 2012; Vescovi & Goodale, 2015). In contrast, there is limited information on the match actions (e.g., tries scored, line breaks) of female Rugby Sevens (Barkell et al., 2016; Barkell et al., 2017; Portillo et al., 2017; Reyneke et al., 2018).

Similar to other team sports, success in Rugby Sevens is multifactorial (Ross et al., 2014), and determined by a mix of technical, tactical, and physical factors; therefore, a variety of physical qualities could contribute to match performance. In women's Sevens athletes competing at different playing levels, performance in various physical tests (10-m acceleration, 40-m sprint, Yo-Yo Intermittent Recovery Test Level 1, vertical jump) showed moderate to large correlations with some measures of match running, such as total distance and maximal speed (Clarke et al., 2017b). However, no information exists on the relationship between physical-test measures and match actions, which could provide additional helpful information to practitioners.

Due to the repeated high-intensity nature of Rugby Sevens, possessing well-developed aerobic and anaerobic fitness qualities could be beneficial for match running in female Rugby Sevens athletes (Clarke et al., 2017b). In addition, since multiple matches are played over two to three days, superior fitness capacities could promote greater recovery between matches and competition days (Stone & Kilding, 2009; Tomlin & Wenger, 2001). To date, there have been no studies investigating the effectiveness of different training programmes for enhancing fitness in female Rugby Sevens athletes; and limited research conducted on male Rugby Sevens athletes (Robineau et al., 2017). While measures of aerobic fitness (e.g., maximal aerobic speed) are usually employed to assess the efficacy of fitness training interventions, adding assessments of maximal sprinting speed would allow the simultaneous assessment of both metabolic and mechanical/neuromuscular characteristics of athletes (Sandford, 2018).

When working with or conducting research on female athletes, it is important to consider that female physiology affected by the menstrual cycle, a biological rhythm regulated by the cyclical variation in endogenous sex hormones (i.e., oestrogen and progesterone). The changing concentrations of these hormones at different stages of the menstrual cycle can affect different body systems and functions (Sims & Heather, 2018), which could consequently influence exercise performance (Constantini et al., 2005; de Jonge, 2003). For example, high levels of oestrogen are associated with an increased oxidative capacity and a decreased dependence on anaerobic pathways for adenosine triphosphate (ATP) production, which leads to lower blood lactate levels (Oosthuyse & Bosch, 2010). In contrast, an increase in progesterone might elevate resting heart rate (Sedlak et al., 2012), basal body temperature, and ventilation (Charkoudian et al., 1999). Unfortunately, there is still no definitive evidence on the effects of the menstrual cycle on athletic performance (Mujika & Taipale, 2019). The only previous study exploring the potential effects of menstrual cycle in female Rugby athletes (Miskec et al., 1997) reported no significant differences between early follicular and luteal phase on anaerobic power output during repeated high-intensity, intermittent exercise on a cycle ergometer. However, no other physical tests were conducted that could have been more representative of the Rugby demands (e.g., speed, strength).

Thesis aims

Based on the identified gaps in the female Rugby Sevens literature, the objectives of this Thesis were to:

- Summarise the current body of literature addressing match demands (match running and physiological demands), anthropometric characteristics, and physical qualities in female Rugby Sevens, and to highlight differences between competition levels and playing positions.

- Evaluate the association between physical-test measures with various match-running and match-action measures.
- Investigate the effectiveness of different running training programmes on the locomotor profile of female Rugby Sevens athletes.
- Investigate the potential effect of menstrual cycle phase on physical performance in female Rugby athletes.

Significance of the Thesis

The findings of this Thesis will increase the overall understanding of the women's Rugby Sevens game, with a particular focus on performance enhancement. Firstly, knowledge of the match running demands, anthropometric characteristics, and physical qualities of players for different competition levels would provide useful information on the physical requirements needed to perform at the highest level of competition and to transition between levels. This information could be useful for coaches and athletes in athletic conditioning and preparation. In addition, understanding the demands specific to backs and forwards might be beneficial to further improve athletes' preparation. The evaluation of the relationships between physical-test measures with match-running and match-actions activities could assist physical training programming to enhance match performance, as well as confirm which tests are useful predictors of performance.

Because of the high running demands of Rugby Sevens, knowledge of the effects of different fitness training programmes on athletes' locomotor profile would allow a more complete evaluation of athletes' fitness adaptations and subsequent implications on performance. Finally, increasing the understanding of the potential effects of the menstrual cycle on physical performance will likely be helpful for interpreting physical-test results and for training prescription.

Thesis structure

The Thesis comprises six chapters (Figure 2). Chapter 1 is a general introduction and outlines the rationale and aims of the Thesis, as well as the significance of the Thesis findings. Chapter 2 consists of a systematic review of the female Rugby Sevens literature describing athletes' anthropometric characteristics, physical qualities, and match demands (match running and physiological responses). Chapters 3 explores the association between physical-test performance with match running and match actions. Chapter 4 and 5 focus on physical performance enhancements; specifically, Chapter 4 investigates the effects of two fitness training programmes on athlete locomotor profile and Chapter 5 explores the potential effects of menstrual-cycle phase on physical performance. The final chapter (Chapter 6) summarises the key findings of the Thesis, discusses the limitations, and provides future research directions. All chapters except for Chapter 1 and Chapter 6 are standalone pieces of research work. Chapter 2, Chapter 3, and Chapter 5 include studies that are published or accepted for publication in peer-reviewed journals.

The Thesis is supported by additional work presented in the appendices. The appendices include a published manuscript that details the relationship between performance in the 1.2 km shuttle run test (also known as Bronco) and other popular fitness tests used in Rugby (Appendix A). The Bronco test was employed in Chapter 3 and 5 as a measure of running fitness. Due to the limited sample size available on female Rugby athletes, the study was conducted on male Rugby Sevens and Rugby Union athletes and is the reason why it features as appendix rather than a methodological chapter of the Thesis.

Throughout the Thesis, some words have been used interchangeably for readability and to suit the requirements of peer-reviewed journals. The key ones are: female and women; player and athlete; physical qualities and physical-test measures; and professional and elite. Due to the nature of the Thesis with publications, there are some repetitions across Chapters.

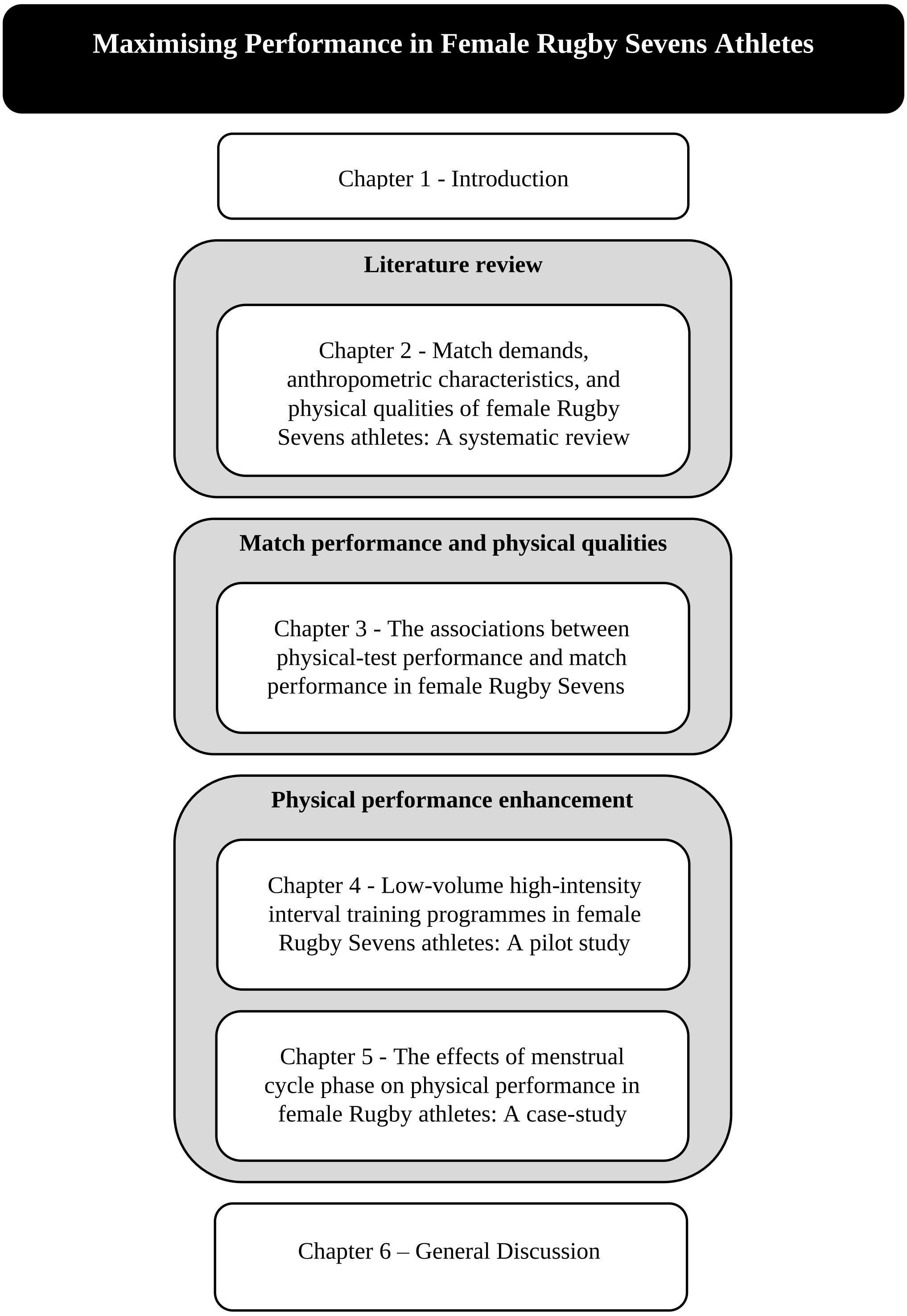

Figure 2. Thesis structure schematic

Literature review

Sella FS, McMaster DT, Beaven CM, Gill ND, Hébert-Losier K. Match demands, anthropometric characteristics, and physical qualities of female Rugby Sevens athletes: A systematic review, *Journal of Strength and Conditioning Research*, 33 (12), 3463-3474, 2019.

Chapter 2 - Match demands, anthropometric characteristics, and physical qualities of female Rugby Sevens athletes: A systematic review

Introduction

Rugby Sevens is an intermittent field-based team sport characterised by high-intensity activities and collisions (Ross et al., 2014). Although played under similar rules and field dimensions as Rugby Union, Rugby Sevens consists of two teams of seven on-field players playing two 7-minute halves separated by a 2-minute halftime, as opposed to 15 players playing two 40-minute halves separated by 10–15 minutes in Rugby Union. Rugby Sevens matches are played in a tournament style, with 5–6 matches played over two or three days. The top teams in the world compete annually in the Men's and Women's Sevens World Series, which comprise 10 and six international tournaments, respectively ("About HSBC World Rugby Sevens Series," 2019). Of note, from the start of the 2016–2017 World Series, the duration of Cup finals' matches has changed from two 10-minute halves to two 7-minute halves for player welfare ("Global Law Trials Set for 2017," 2019).

Since the inclusion of Rugby Sevens in the 2016 Olympic Games, the popularity of the game has grown rapidly worldwide (Clarke et al., 2014; Engebretsen & Steffen, 2010; Goodale et al., 2016; Goodale et al., 2017; Griffin et al., 2017b; Reyneke et al., 2018; Vescovi & Goodale, 2015) resulting in a number of countries creating national Rugby Sevens programmes (Vescovi & Goodale, 2015). The growth of Rugby Sevens has also led to an increase in scientific interest, as reflected by the emergence of Rugby Sevens research (Barkell et al., 2016; Henderson et al., 2018). However, a greater number of studies have addressed the men's Rugby Sevens game compared with the women's game. Because differences between male and female Rugby Sevens athletes have been observed in terms of anthropometric characteristics (Clarke et al., 2017b), physical qualities (Clarke et al., 2017b), match demands (Clarke et al., 2017b), and technical and tactical skills associated with success (Barkell et al., 2016), specific considerations are needed for female Rugby Sevens athletes. Furthermore, it is well known that the menstrual or contraceptive profiles of female athletes can impact sporting performance (Sims & Heather, 2018), warranting specific research on the female athlete.

A number of recent investigations have described the match demands (Clarke et al., 2015a; Clarke et al., 2017b; Goodale et al., 2017; Malone et al., 2020; Misseldine et al., 2021; Portillo et al., 2014; Reyneke et al., 2018; Suarez-Arrones et al., 2012; Vescovi & Goodale, 2015), anthropometric characteristics (Agar-Newman et al., 2017; Clarke et al., 2017b; Goodale et al., 2016; Ohya et al., 2015), and physical qualities of female Rugby Sevens athletes (Agar-Newman et al., 2017; Clarke et al., 2017b; Goodale et al., 2016; Leite et al., 2016; Ohya et al., 2015; Vescovi & Goodale, 2015). Given the differences found between athletes competing at an international and national level (Clarke et al., 2017b; Portillo et al., 2014; Vescovi & Goodale, 2015), understanding the match demands and the physical requirements for each competition level is fundamental for developing effective training programmes (Ross et al., 2015a; Suarez-Arrones et al., 2012). This understanding is also useful for informing coaches and supporting staff of the requirements needed to dominate at the highest level (Sirotic et al., 2009) and transition between competition levels. Furthermore, as Rugby Sevens athletes can be categorised as backs and forwards, knowledge of the position-specific demands may have important implications to further enhance athletes' preparation (Clarke, 2016). The aim of this systematic review is therefore to summarise the current body of female Rugby Sevens literature, addressing the match demands, anthropometric characteristics, and physical qualities of athletes, and to highlight differences between competition levels and playing positions.

Methods

Experimental approach to the problem

Search Strategy. This systematic review adheres to the structure and reporting guidelines of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Moher et al., 2009). Four electronic databases (PubMed, SciVerse Scopus®, SPORTDiscus™, and Web of Science®) were searched systematically on June 21, 2018, using the following keywords and Boolean operators: "football AND seven* AND female AND NOT/NOT soccer." The reference lists of all articles meeting inclusion were searched manually for additional articles of relevance. The electronic databases and key journals in the field (e.g., Journal of Strength and Conditioning Research and the International Journal of Sports Physiology and Performance) were monitored until September 30, 2018.

Participants

Inclusion Criteria. Only original peer-reviewed research articles written in English reporting match demands, anthropometric characteristics, or physical qualities of senior (>18 years) female Rugby Sevens athletes were included. Conference abstracts, letters to the editor, book chapters, and Thesis publications were excluded. Approval was granted from the University of Waikato Research Ethics Committee.

Procedures

Study Selection Process. One author (F.S.S.) completed the study screening and selection process. Duplicate articles identified through the electronic database search were removed first. Thereafter, all titles, abstracts, and full texts were sequentially screened for inclusion criteria. The study selection process was replicated for articles that were included through the manual search (Figure 3).

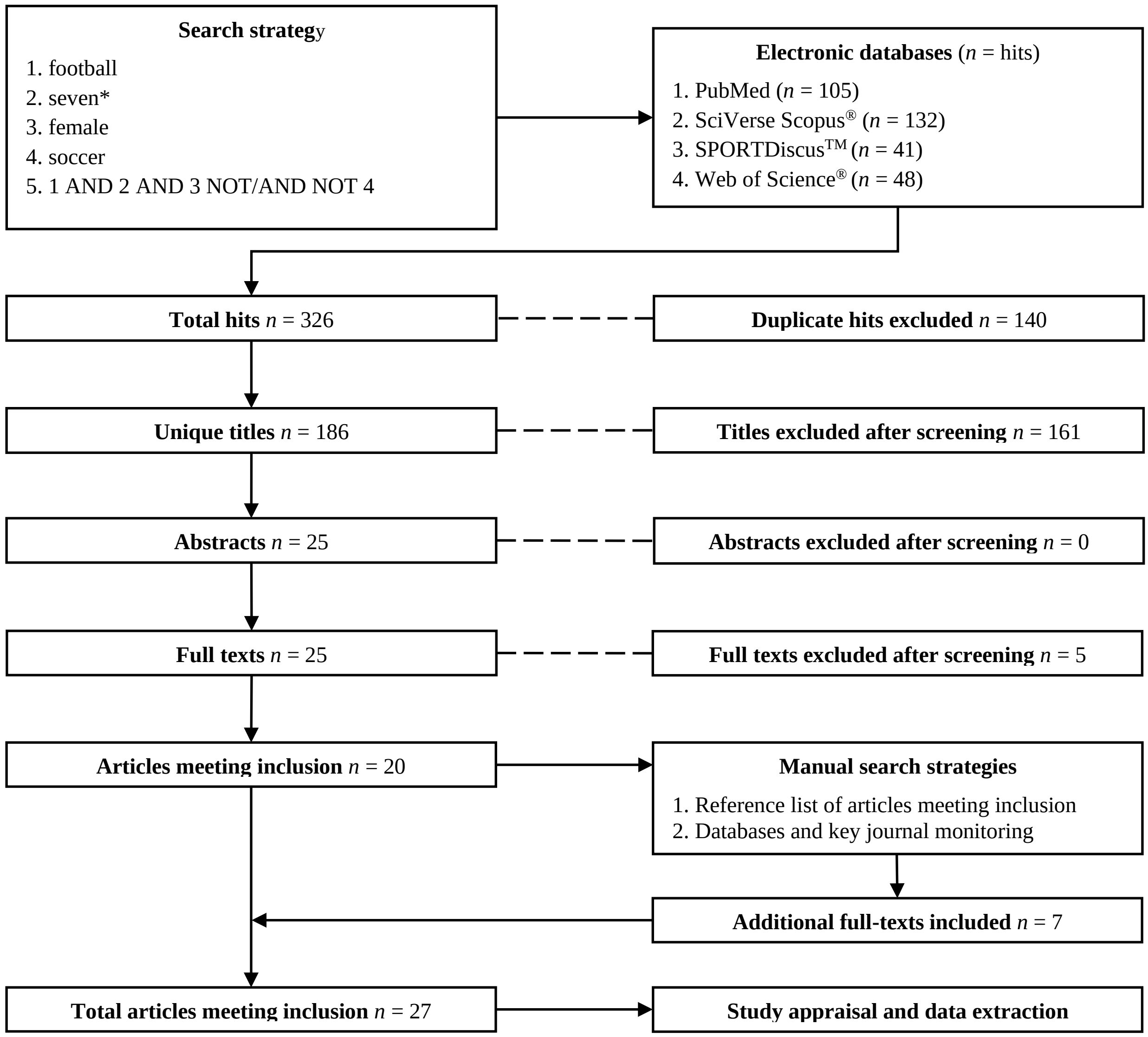

Figure 3. Flow diagram of the search strategy and article selection process

Study Quality Assessment. The methodological quality of the included articles was assessed using a modified version of the Downs and Black quality assessment checklist (Downs & Black, 1998). Modified versions of the checklist have been used to assess the quality of sport-related articles (Hébert-Losier & Holmberg, 2013; Hébert-Losier et al., 2014; Hébert-Losier et al., 2017) based on reporting, external validity, internal validity (bias and confounding), and power. The specific modifications and scoring criteria implemented for our systematic review are outlined in the Appendix B1 (Study quality assessment). A final Quality Index score for each study was computed as follows, where a higher percentage reflects a superior methodological quality:

$$Quality\ Index\ (\%) = \frac{Total\ number\ of\ points}{Total\ number\ of\ applicable\ points} \times 100$$

Studies were categorised as strong, moderate, or limited quality when reaching thresholds of 75, 50, 25%, and poor when <25% (Hignett, 2003; Simpson et al., 2015). The design of each study was classified first as experimental or observational and then as randomised controlled trial, cross-sectional (measures taken single occasion or multiple occasions without comparisons), or cohort (measures taken multiple occasions with comparisons) (McKeon et al., 2006; Vandenbroucke et al., 2007; von Elm et al., 2007). No articles were excluded from this review based on the quality score or study design. Two authors (F.S.S. and K.H-L.) assessed the quality and classified the design of studies independently. Results were subsequently compared. In case of disagreement between authors without reaching a consensus rating, a third author was available to resolve differences in opinion but was not needed.

Data Extraction. Data were extracted by one author (F.S.S.), with the completeness of extraction verified by a second author (K.H-L.). All data were organised and analysed using Microsoft Excel 2016 (Microsoft Corporation, Redmont, WA, USA).

Measures of external and internal load collected with the use of the Global Positioning System (GPS) and heart rate (HR) monitors were extracted as match demand metrics. Total (m) and relative ($m \cdot min^{-1}$) match distance; total (m) and relative ($m \cdot min^{-1}$) distance covered at different intensities; and maximal speed ($m \cdot s^{-1}$), number of sprints, and number of accelerations were considered external load metrics. Maximal and mean HR ($b \cdot min^{-1}$) and percentage time (%) spent in different heart zones were extracted as internal load metrics. Only GPS data of full games (14 minutes) were used to describe total match distance, total distance covered at different intensities, number of sprints, and number of accelerations. The GPS and HR files of athletes who played ≥7 minutes of a full match were used to describe relative match distance, relative distance covered at different intensities, maximal speed, maximal and mean HR, and percentage time spent in different heart zones. The analysis did not consider Cup finals when matches were 20 minutes long (i.e., previous regulations).

All speed variables were expressed in $m \cdot s^{-1}$, with speed zones of 5.5 and 5.6 $m \cdot s^{-1}$ pooled together. Sprints were defined as running efforts above 5.5 $m \cdot s^{-1}$, whereas accelerations were defined as efforts above 1.5 $m \cdot s^{-2}$. No metabolic power measures or collision data were considered because their validity in Rugby Sevens has not yet been established (Clarke et al., 2017c; Vescovi & Goodale, 2015). Height, body mass, and body composition data were extracted as anthropometric characteristics. Results from physical tests assessing acceleration, maximal speed, power, strength, and aerobic capacities were extracted to represent physical quality metrics.

Data were grouped in categories based on the competition level (elite and nonelite) and playing position (backs and forwards). Elite athletes were those defined as competing in international (I) tournaments as part of a national team. Nonelite athletes were those defined as competing domestically or in national (N) tournaments. Across studies, mean and SD values (mean ± SD) specific to each competition level and playing position were computed and weighted by sample size, with the exception of match demand data, where weighting was based on the number of GPS and HR files analysed.

Statistical analysis

To evaluate differences between competition levels and playing positions, Hedges' g effect sizes (ESs) with 95% confidence intervals (CIs) were calculated, with the reference group for comparison being elite or international, and backs. Effect size magnitudes were interpreted as trivial <0.20, small 0.20–0.59, moderate 0.60–1.19, large 1.20–1.99, very large 2.00–3.99, and extremely large ≥4.00 (Hopkins et al., 2009). Where the 95% CI overlapped small positive and negative effects (±0.20), the difference was deemed unclear (Goodale et al., 2016). For clarity in the tables, clear effects and their magnitudes were reported using superscript letters: ^{T} trivial, ^{S} small, ^{M} moderate, ^{L} large, ^{V} very large, and ^{X} extremely large (Hébert-Losier et al., 2015).

Results

Search strategy, study characteristics, and quality scores

The initial electronic database search generated 326 hits, with a total of 27 articles meeting inclusion (Figure 3). A summary of the research design, Quality Index, participants, and variables of interest for each study is reported in Table 1. Of the 27 studies reviewed, 18 (67%) had an observational cross-sectional design (Agar-Newman et al., 2017; Clarke et al., 2015a; Clarke et al., 2017b, 2017c; Clarke et al., 2014; Goodale et al., 2016; Goodale et al., 2017; Griffin et al., 2017a; Griffin et al., 2017b; Leite et al., 2016; Malone et al., 2020; Misseldine et al., 2021; Ohya et al., 2015; Portillo et al., 2014; Reyneke et al., 2018; Suarez-Arrones et al., 2012; Valenzuela et al., 2018; Vescovi & Goodale, 2015), seven (26%) had an observational cohort design (Clarke et al., 2017a; Clarke et al., 2015b, 2015c; Fuller et al., 2017; Gathercole et al., 2015; Ma et al., 2016; Mirsafaei Rizi et al., 2017), and two (7%) were experimental randomised controlled trials (Del Coso et al., 2013; Portillo et al., 2017). The average Quality Index of the studies reviewed was 68 ± 13% (range 42–91). Ten studies (37%) were categorised as being of strong (Del Coso et al., 2013; Fuller et al., 2017; Goodale et al., 2017; Griffin et al., 2017b; Ma et al., 2016; Malone et al., 2020; Mirsafaei Rizi et al., 2017; Misseldine et al., 2021; Portillo et al., 2017; Portillo et al., 2014), 15 (56%) as moderate (Agar-Newman et al., 2017; Clarke et al., 2015a; Clarke et al., 2015b, 2015c; Clarke et al., 2017b, 2017c; Clarke et al., 2014; Goodale et al., 2016; Griffin et al., 2017a; Leite et al., 2016; Ohya et al., 2015; Reyneke et al., 2018; Suarez-Arrones et al., 2012; Valenzuela et al., 2018; Vescovi & Goodale, 2015), and two (7%) as limited quality (Clarke et al., 2017a; Gathercole et al., 2015). The average Quality Index for studies reporting match demands was 73 ± 11% (range 56–90), anthropometric characteristics 69 ± 13% (range 42–91), and physical qualities 64 ± 8% (range 48–79). The complete quality assessment for each study can be found in the Appendix B2. The inability to determine the participants' source population, lack of menstrual or contraceptive phase data, and lack of adequate adjustments for confounding variables were the main quality issues.

Participants and themes

The elite group was the most researched, with 19 studies (Agar-Newman et al., 2017; Clarke et al., 2015a; Clarke et al., 2017a; Clarke et al., 2017c; Clarke et al., 2014; Del Coso et al., 2013; Fuller et al., 2017; Gathercole et al., 2015; Goodale et al., 2016; Goodale et al., 2017; Griffin et al., 2017a; Griffin et al., 2017b; Malone et al., 2020; Misseldine et al., 2021; Ohya et al., 2015; Portillo et al., 2017; Reyneke et al., 2018; Suarez-Arrones et al., 2012; Valenzuela et al., 2018), followed by six studies addressing elite and nonelite (Clarke et al., 2015b, 2015c; Clarke et al., 2017b; Ma et al., 2016; Portillo et al., 2014; Vescovi & Goodale, 2015) and two studies on nonelite only (Leite et al., 2016; Mirsafaei Rizi et al., 2017). A total of 1,139 female Rugby Sevens athletes were considered across the 27 studies, comprising 976 elite (86%) and 163 nonelite (14%) athletes. Data specific on playing positions were clearly reported in five studies (Agar-Newman et al., 2017; Goodale et al., 2017; Ma et al., 2016; Misseldine et al., 2021; Ohya et al., 2015) (Table 1). The average number of participants in each study was 42 ± 106; however, owing to the range (7–566 participants) and because 25 of the 27 studies had less than 42 participants, the median value (x = 22) may be more representative (Manikandan, 2011).

The weighted mean age of participants across the studies was 24.5 ± 1.2 years. One study did not report age (Vescovi & Goodale, 2015), and another study only indicated that participants were aged 18 years older (Clarke et al., 2017b). A total of 14 studies (Clarke et al., 2015a; Clarke et al., 2017a; Clarke et al., 2015b, 2015c; Clarke et al., 2017b; Clarke et al., 2014; Del Coso et al., 2013; Fuller et al., 2017; Ma et al., 2016; Mirsafaei Rizi et al., 2017; Ohya et al., 2015; Portillo et al., 2014; Vescovi & Goodale, 2015) explicitly indicated the country of origin of participants. Among the countries considered, Australia was the most represented (Clarke et al., 2015a; Clarke et al., 2017a; Clarke et al., 2015b, 2015c; Clarke et al., 2017b; Clarke et al., 2014; Fuller et al., 2017), followed by Spain (Del Coso et al., 2013; Fuller et al., 2017; Portillo et al., 2017; Portillo et al., 2014). Only one study specified involving athletes from multiple countries (Fuller et al., 2017). When considering the variables of interest, 10 studies reported match demands data with playing time information (Clarke et al., 2017b; Clarke et al., 2014; Del Coso et al., 2013; Goodale et al., 2017; Malone et al., 2020; Portillo et al., 2014; Reyneke et al., 2018; Suarez-Arrones et al., 2012; Vescovi & Goodale, 2015); 26 reported anthropometric characteristics (Agar-Newman et al., 2017; Clarke et al., 2015a; Clarke et al., 2017a; Clarke et al., 2015b, 2015c; Clarke et al., 2017b, 2017c; Clarke et al., 2014; Del Coso et al., 2013; Fuller et al., 2017; Gathercole et al., 2015; Goodale et al., 2016; Goodale et al., 2017; Griffin et al., 2017a; Griffin et al., 2017b; Leite et al., 2016; Ma et al., 2016; Malone et al., 2020; Mirsafaei Rizi et al., 2017; Misseldine et al., 2021; Ohya et al., 2015; Portillo et al., 2017; Portillo et al., 2014; Reyneke et al., 2018; Suarez-Arrones et al., 2012; Valenzuela et al., 2018); and 14 reported physical qualities of female Rugby Sevens athletes (Agar-Newman et al., 2017; Clarke et al., 2015a; Clarke et al., 2015c; Clarke et al., 2017b; Clarke et al., 2014; Del Coso et al., 2013; Gathercole et al., 2015; Goodale et al., 2016; Leite et al., 2016; Misseldine et al., 2021; Ohya et al., 2015; Suarez-Arrones et al., 2012; Valenzuela et al., 2018; Vescovi & Goodale, 2015).

Table 1. Summary of the studies reviewed (*n* = 27).

Article	Study Design	Quality Index	Participants				Variables of Interest
			n	Level	Age (y)	Country	
Agar-Newman et al., 2017	Observational Cross-sectional	70% (16/23)	13 11	Elite – WS (B) Elite – WS (F)	21.3 ± 3.5 24.5 ± 3.9	NS NS	Anthropometric characteristics Physical qualities (speed, power, strength, aerobic)
Clarke et al., 2014	Observational Cross-sectional	73% (16/22)	22	Elite – WS	25.0 ± 5.0	Australia	Match demands (GPS) Anthropometric characteristics Physical qualities (aerobic)
Clarke et al., 2015c	Observational Cohort	67% (16/24)	12 10	Elite – WS Non-Elite	22.3 ± 2.5 24.4 ± 4.3	Australia Australia	Anthropometric characteristics Physical qualities (power)
Clarke et al., 2015a	Observational Cross-sectional	64% (14/22)	12	Elite – WS	23.5 ± 4.9	Australia	Anthropometric characteristics Physical characteristics (aerobic)
Clarke et al., 2015b	Observational Cohort	54% (13/24)	12 10	Elite – WS Non-Elite	22.3 ± 2.5 24.4 ± 4.3	Australia Australia	Anthropometric characteristics
Clarke et al., 2017b	Observational Cross-sectional	56% (13/23)	11 22	Elite – WS Non-Elite	> 18 > 18	Australia Australia	Match demands (GPS) Anthropometric characteristics Physical qualities (speed, power, aerobic)
Clarke et al., 2017a	Observational Cohort	42% (10/24)	23	Elite – WS	24.0 ± 5.0	Australia	Anthropometric characteristics
Clarke et al., 2017c	Observational Cross-sectional	53% (10/19)	12	Elite – WS	22.8 ± 3.6	NS	Anthropometric characteristics
Del Coso et al., 2013	Experimental Randomised Controlled	79% (22/28)	16	Elite	23.0 ± 2.0	Spain	Match demands (GPS, HR) Anthropometric characteristics Physical qualities (power)
Fuller et al., 2017	Observational Cohort	91% (20/22)	197 221 148	Elite – WS Elite – WS Elite – Oly	24.3 ± 3.6 24.6 ± 4.0 26.2 ± 4.0	Multiple[a] Multiple[b] Multiple[c]	Anthropometric characteristics
Gathercole et al., 2015	Observational Cohort	48% (11/23)	12	Elite	23.6 ± 4.3	NS	Anthropometric characteristics Physical qualities (power)
Goodale et al., 2016	Observational Cross-sectional	61% (14/23)	12 12	Elite – WS (HM) Elite – WS (LM)	24.3 ± 3.1 21.2 ± 4.3	NS NS	Anthropometric characteristics Physical qualities (speed, power, strength, aerobic)
Goodale et al., 2017	Observational Cross-sectional	86% (18/21)	11 9	Elite – WS (B) Elite – WS (F)	24.0 ± 3.6	NS NS	Match demands (GPS, HR) Anthropometric characteristics
Griffin et al., 2017b	Observational Cross-sectional	78% (17/22)	24	Elite – WS	24.0 ± 5.0	NS	Anthropometric characteristics

Table 1. Continued.

Article	Study Design	Quality Index	Participants				Variables of Interest
			n	Level	Age (y)	Country	
Griffin et al., 2017a	Observational Cross-sectional	68% (15/22)	24	Elite – WS	24.0 ± 5.0	NS	Anthropometric characteristics
Leite et al., 2016	Observational Cross-sectional	57% (12/21)	7	Non-Elite	21.3 ± 1.5	NS	Anthropometric characteristics Physical qualities (power, strength)
Ma et al., 2016	Observational Cohort	86% (19/22)	10 7 44 33	Elite (B) Elite (F) Non-Elite (B) Non-Elite (F)	24.1 ± 3.4 23.8 ± 8.3 23.5 ± 5.0 23.7 ± 5.6	USA USA USA USA	Anthropometric characteristics
Malone et al., 2020	Observational Cross-sectional	90% (19/21)	27	Elite – WS	24.4 ± 2.1	NS	Match demands (GPS, HR) Anthropometric characteristics
Misseldine et al., 2021	Observational Cross-sectional	76% (16/21)	7 5	Elite (B) Elite (F)	24.6 ± 4.7 27.0 ± 2.5	NS NS	Match demands (GPS) Anthropometric characteristics Physical qualities (speed)
Ohya et al., 2015	Observational Cross-sectional	64% (14/22)	12 11	Elite (B) Elite (F)	23.1 ± 4.1	Japan Japan	Anthropometric characteristics Physical qualities (speed, power)
Portillo et al., 2014	Observational Cross-sectional	76% (16/21)	10 10	Elite Non-Elite	26.3 ± 4.0 32.1 ± 6.4	Spain Spain	Match demands (GPS, HR) Anthropometric characteristics
Portillo et al., 2017	Experimental Randomised Controlled	86% (24/28)	16	Elite	23.0 ± 2.0	Spain	Anthropometric characteristics
Reyneke et al., 2018	Observational Cross-sectional	71% (15/21)	15	Elite – WS	24.3 ± 3.9	NS	Match demands (GPS) Anthropometric characteristics
Mirsafaei Rizi et al., 2017	Observational Cohort	78% (18/23)	14	Non-Elite	20.3 ± 1.2	Hong Kong	Anthropometric characteristics
Suarez-Arrones et al., 2012	Observational Cross-sectional	64% (14/22)	12	Elite	27.8 ± 4.0	NS	Match demands (GPS, HR) Anthropometric characteristics Physical qualities (aerobic)
Valenzuela et al., 2018	Observational Cross-sectional	65% (15/23)	7 7	Elite – Oly (HP) Elite – Oly (LP)	27.0 ± 5.0 28.0 ± 5.0	NS NS	Anthropometric characteristics Physical qualities (power)
Vescovi & Goodale, 2015	Observational Cross-sectional	57% (13/23)	16 13	Elite Non-Elite	NS NS	Canada Canada	Match demands (GPS, HR) Physical qualities (speed, aerobic)

B = Backs, F = Forwards, GPS = Global Positioning System, HM = High playing minutes, HP = High-power, HR = Heart rate, LM = Low playing minutes, LP = Low-power, NS = Not specified, Oly = Olympic Games, WS = World Series.

[a]Australia, Canada, China, England, Fiji, France, New Zealand, Russia, South Africa, Spain, USA.
[b]Australia, Canada, England, Fiji, France, Ireland, Japan, New Zealand, Russia, Spain, USA.
[c]Australia, Brazil, Canada, Colombia, Fiji, France, Great Britain, Japan, Kenya, New Zealand, Spain, USA.

Match demands

Ten studies reported GPS match demand data (Clarke et al., 2017b; Clarke et al., 2014; Del Coso et al., 2013; Goodale et al., 2017; Malone et al., 2020; Misseldine et al., 2021; Portillo et al., 2014; Reyneke et al., 2018; Suarez-Arrones et al., 2012; Vescovi & Goodale, 2015) (see Appendix B3). Six of these studies (Del Coso et al., 2013; Goodale et al., 2017; Malone et al., 2020; Portillo et al., 2014; Suarez-Arrones et al., 2012; Vescovi & Goodale, 2015) also reported HR responses (see Appendix B4).

During matches, elite athletes covered greater total distances (1,623 ± 17 vs. 1,363 ± 222 m, ES = 4.46) and relative distances (98 ± 12 vs. 94 ± 4 $m \cdot min^{-1}$, ES = 0.36) in comparison with their nonelite counterparts. Elite athletes also completed more sprints (3.9 ± 1.2 vs. 1.9 ± 1.4 sprints, ES = 1.65) and accelerations (12.4 ± 1.5 vs. 10.5 ± 3.1 accelerations, ES = 1.15) per match and reached greater maximal speeds (7.3 ± 0.4 vs. 7.0 ± 0.5 $m \cdot s^{-1}$, ES = 0.71). Elite athletes covered more total distance in each of the speed thresholds analysed (ES = 0.62 to 5.52) and more relative distance above 5.5 $m \cdot s^{-1}$ (ES = 1.64) and between 4.4 and 5.5 $m \cdot s^{-1}$ (ES = 2.44). By contrast, nonelite athletes covered more relative distance between 2.2 and 4.4 $m \cdot s^{-1}$ (ES = -0.24) and more distance below 2.2 $m \cdot s^{-1}$ (ES = -0.76) (Table 2).

Lower maximal (187 ± 1 vs. 190 ± 7 $b \cdot min^{-1}$, ES = -0.97) and mean (170 ± 2 vs. 174 ± 11 $b \cdot min^{-1}$, ES = -0.82) HR values were registered in international matches compared with the national level. When considering time spent in different HR zones, elite athletes spent more time between 80 and 90% HRmax (ES = 1.18), between 60 and 70% HRmax (ES = 0.43), and below 60% HRmax (ES = 2.05). On the other hand, nonelite athletes spent more time between 90 and 100% HRmax (ES = -1.24) and between 70 and 80% HRmax (ES = -0.92) (Table 3).

During international matches, backs covered on average 1728 m, completed 4.5 sprints, and performed 14.0 accelerations per game, whereas forwards covered 1,422 m, completed 2.5 sprints, and performed 11.0 accelerations. However, no comparisons were possible because no SD values were reported (Table 2). Backs reached greater maximal speeds than forwards (7.4 ± 0.3 vs. 7.1 ± 0.4 $m \cdot s^{-1}$, ES = 0.86) during matches; by contrast, total relative distance was similar between playing positions. When considering distance covered in different speed zones, no comparisons were possible for total distance covered between 4.4 and 5.5 $m \cdot s^{-1}$ and above 5.5 $m \cdot s^{-1}$. Backs covered more relative distance above 5.0 $m \cdot s^{-1}$ (ES = 0.25) and forwards between 3.5 and 5.0 $m \cdot s^{-1}$ (ES = -0.55) (Table 2).

In international matches, backs registered a higher mean HR (172 ± 2 vs. 170 ± 1 $b \cdot min^{-1}$, ES = 1.83) compared with forwards. On average, international backs and forwards had maximal HR of 188 and 186; however, no comparisons were possible (Table 3). When considering time spent in different HR zones, backs spent more time between 90 and 100% HRmax (ES = 0.30), between 80 and 90% HRmax (ES = 0.90), and below 60% HRmax (ES = 1.00). By contrast, forwards spent more time between 70 and 80% HRmax (ES = -0.66) and between 60 and 70% HRmax (ES = -0.98) (Table 3).

Table 2. Summary of GPS match data of female Rugby Sevens athletes.

Competition Level	Total Distance (m)	Relative Distance ($m \cdot min^{-1}$)	Sprints >5.5 $m \cdot s^{-1}$ (*n*)	Accelerations >1.5 $m \cdot s^{-2}$ (*n*)	Max Speed ($m \cdot s^{-1}$)	Distance covered per speed zone: <3.5 $m \cdot s^{-1}$	3.5-5.0 $m \cdot s^{-1}$	5.0-5.5 $m \cdot s^{-1}$	>5.5 $m \cdot s^{-1}$	<2.2 $m \cdot s^{-1}$	2.2-4.4 $m \cdot s^{-1}$	4.4-5.5 $m \cdot s^{-1}$	>5.5 $m \cdot s^{-1}$
International	1623 ± 17	98 ± 12	3.9 ± 1.2	12.4 ± 1.5	7.3 ± 0.4	1021 ± 32 m	439 ± 1 m	86 ± 22 m	116 ± 8 m	36 ± 2 $m \cdot min^{-1}$	36 ± 5 $m \cdot min^{-1}$	14 ± 0 $m \cdot min^{-1}$	7 ± 1 $m \cdot min^{-1}$
(no. files)	(296)	(845)	(296)	(279)	(741)	(46)	(46)	(46)	(296)	(134)	(134)	(384)	(190)
National	1363 ± 222	94 ± 4	1.9 ± 1.4	10.5 ± 3.1	7.0 ± 0.5	961 ± 168 m	356 ± 94 m	46 ± 33 m	47 ± 39 m	39 ± 6 $m \cdot min^{-1}$	38 ± 12 $m \cdot min^{-1}$	10 ± 4 $m \cdot min^{-1}$	4 ± 3 $m \cdot min^{-1}$
(no. files)	(21)	(192)	(21)	(21)	(189)	(21)	(21)	(21)	(21)	(78)	(78)	(78)	(78)
ES	4.46^{X}	0.36^{S}	1.65^{L}	1.15^{M}	0.71^{M}	0.62^{M}	1.59^{L}	1.55^{L}	5.52^{X}	-0.76^{M}	-0.24^{S}	2.44^{V}	1.64^{L}
[95% CI]	[3.89,5.01]	[0.21,0.52]	[1.18,2.10]	[0.69,1.60]	[0.55,0.87]	[0.09,1.14]	[0.99,2.15]	[0.95,2.10]	[4.89,6.12]	[-1.04,-0.47]	[-0.52,0.04]	[2.15,2.73]	[1.34,1.94]

Playing Position (International Level)	Total Distance (m)	Relative Distance ($m \cdot min^{-1}$)	Sprints >5.5 $m \cdot s^{-1}$ (*n*)	Accelerations >1.5 $m \cdot s^{-2}$ (*n*)	Max Speed ($m \cdot s^{-1}$)	Distance covered per speed zone: 4.4-5.5 $m \cdot s^{-1}$	≥5.5 $m \cdot s^{-1}$	<3.5 $m \cdot s^{-1}$	3.5-5.0 $m \cdot s^{-1}$	>5.0 $m \cdot s^{-1}$
Backs	1728	88 ± 4	4.5	14.0	7.4 ± 0.3	223 m	133 m	61 ± 7 $m \cdot min^{-1}$	15 ± 5 $m \cdot min^{-1}$	10 ± 4 $m \cdot min^{-1}$
(no. files)	(131)	(122)	(131)	(131)	(253)	(131)	(131)	(103)	(103)	(103)
Forwards	1422	88 ± 3	2.5	11.0	7.1 ± 0.4	174 m	102 m	61 ± 8 $m \cdot min^{-1}$	18 ± 6 $m \cdot min^{-1}$	9 ± 4 $m \cdot min^{-1}$
(no. files)	(119)	(100)	(119)	(119)	(219)	(119)	(119)	(88)	(88)	(88)
ES	NA	0.00	NA	NA	0.86^{M}	NA	NA	0.00	-0.55^{S}	0.25^{S}
[95% CI]		[-0.26,0.26]			[0.67,1.04]			[-0.28,0.28]	[-0.83,-0.26]	[-0.04,0.53]

Data are presented as mean or mean ± SD. Pooled based on number of GPS files analysed.
CI = Confidence interval, ES = Effect size, Max = Maximal, NA = Data not available.

^{T}trivial, ^{S}small, ^{M}moderate, ^{L}large, ^{V}very large, ^{X}extremely large.

Table 3. Summary of HR match responses of female Rugby Sevens athletes.

Competition Level	Max HR (beats·min^{-1})	Mean HR (beats·min^{-1})	HR Zones (% time)				
			<60% HR max	60-70% HR max	70-80% HR max	80-90% HR max	90-100% HR max
International	187 ± 1	170 ± 2	1.0 ± 0.3	7.6 ± 6.6	13.9 ± 4.8	40.1 ± 6.6	36.0 ± 15.2
(no. files)	(480)	(671)	(487)	(487)	(487)	(621)	(487)
National	190 ± 7	174 ± 11	0.4 ± 0.2	4.9 ± 1.4	18.1 ± 0.2	32.5 ± 5.7	54.6 ± 14.2
(no. files)	(104)	(104)	(52)	(52)	(52)	(130)	(130)
ES	-0.97^{M}	-0.82^{M}	2.05^{V}	0.43^{S}	-0.92^{M}	1.18^{M}	-1.24^{L}
[95% CI]	[-1.19,-0.75]	[-1.03,-0.61]	[1.74,2.36]	[0.14,0.72]	[-1.21,-0.63]	[0.98,1.37]	[-1.44,-1.03]
Playing Positions (International Level)							
Backs	188	172 ± 2	1.2 ± 0.1	5.5 ± 3.1	13.2 ± 1.9	44.9 ± 6.1	35.7 ± 11.8
(no. files)	(131)	(234)	(234)	(234)	(234)	(234)	(234)
Forwards	186	170 ± 1	1.1 ± 0.1	11.4 ± 8.1	16.1 ± 6.1	40.8 ± 1.5	31.5 ± 16.0
(no. files)	(119)	(207)	(207)	(207)	(207)	(207)	(207)
ES	NA	1.83^{L}	1.00^{M}	-0.98^{M}	-0.66^{M}	0.90^{M}	0.30^{S}
[95% CI]		[1.61,2.05]	[0.80,1.20]	[-1.18,-0.79]	[-0.85,-0.47]	[0.70,1.09]	[0.11,0.49]

Data are presented as mean or mean ± SD. Pooled based on number of HR files analysed.
CI = Confidence interval, ES = Effect size, HR = Heart rate, Max = Maximal, NA = Data not available.

^{T}trivial, ^{S}small, ^{M}moderate, ^{L}large, ^{V}very large, ^{X}extremely large.

Anthropometric characteristics

Height and body mass of athletes were reported in all of the studies reviewed except for one (Vescovi & Goodale, 2015). In addition, measures of body composition were reported in 11 studies (Agar-Newman et al., 2017; Clarke et al., 2015a; Clarke et al., 2017b; Clarke et al., 2014; Del Coso et al., 2013; Goodale et al., 2016; Leite et al., 2016; Ohya et al., 2015; Portillo et al., 2017; Portillo et al., 2014; Valenzuela et al., 2018) (see Appendix B5). Across the studies, sum of 7 skinfolds (mm) (Agar-Newman et al., 2017; Clarke et al., 2015a; Clarke et al., 2017b; Clarke et al., 2014; Goodale et al., 2016), sum of 3 skinfolds (mm) (Leite et al., 2016), body fat (%) (Del Coso et al., 2013; Ohya et al., 2015; Portillo et al., 2017; Portillo et al., 2014), and body mass index ($kg \cdot m^{-2}$) (Valenzuela et al., 2018) were used to describe the body composition of athletes.

Elite athletes were taller (1.68 ± 0.01 vs. 1.66 ± 0.02 m, ES = 1.69) and heavier (67.4 ± 1.5 vs. 66.8 ± 5.0 kg, ES = 0.26) compared with nonelite. Furthermore, elite athletes were leaner, as highlighted by the lower body fat (17.0 ± 1.3 vs. 21.5 ± 5.1%, ES = -1.91) and lower sum of 7 skinfolds (83.8 ± 8.3 vs. 89.0 ± 20.0 mm, ES = -0.46) (Table 4).

At the elite level, backs were shorter (1.66 ± 0.02 vs. 1.67 ± 0.03 m, ES = -0.40), lighter (63.7 ± 2.4 vs. 69.9 ± 2.2 kg, ES = -2.68), and leaner (body fat: 15.4 ± 3.1 vs. 18.1 ± 3.5%, ES = -0.82; sum of 7 skinfolds: 84.4 ± 26.1 vs. 95.0 ± 12.3 mm, ES = -0.51) compared with forwards. Within nonelite athletes, similar height characterised backs and forwards; however, backs were lighter than forwards (66.0 ± 9.5 vs. 71.7 ± 13.9 kg, ES = -0.49) (Table 4). No information about body composition of nonelite backs and forwards was reported.

Table 4. Summary of anthropometric characteristics of female Rugby Sevens athletes.

Competition Level	Height (m)	Body Mass (kg)	Sum of 7 SF (mm)	Body Fat (%)
Elite	1.68 ± 0.01	67.4 ± 1.5	83.8 ± 8.3	17.0 ± 1.3
(n)	(960)	(960)	(93)	(49)
Nonelite	1.66 ± 0.02	66.8 ± 5.0	89.0 ± 20.0	21.5 ± 5.1
(n)	(150)	(150)	(22)	(10)
ES	1.69[L]	0.26[S]	-0.46[S]	-1.91[L]
[95% CI]	[1.50,1.87]	[0.09,0.43]	[-0.92,0.02]	[-2.65,-1.13]
Playing Position (Elite)				
Backs	1.66 ± 0.02	63.7 ± 2.4	84.4 ± 26.1	15.4 ± 3.1
(n)	(42)	(42)	(13)	(12)
Forwards	1.67 ± 0.03	69.9 ± 2.2	95.0 ± 12.3	18.1 ± 3.5
(n)	(34)	(34)	(11)	(11)
ES	-0.40[S]	-2.68[V]	-0.51	-0.82[M]
[95% CI]	[-0.85,0.06]	[-3.27,-2.03]	[-1.30,0.33]	[-1.64,0.06]
Playing Position (Nonelite)				
Backs	1.65 ± 0.06	66.0 ± 9.5		
(n)	(44)	(44)		
Forwards	1.65 ± 0.06	71.7 ± 13.9		
(n)	(33)	(33)		
ES	0.00	-0.49[S]		
[95% CI]	[-0.45,0.45]	[-0.94,-0.03]		

Data are presented as mean ± SD. Pooled based on sample size.
7 SF = Sum of 7 skinfolds, CI = Confidence interval, ES = Effect size.

[T]trivial, [S]small, [M]moderate, [L]large, [V]very large, [X]extremely large.

Physical qualities

Acceleration and Speed. Information on acceleration and speed abilities were reported in six studies (Agar-Newman et al., 2017; Clarke et al., 2017b; Goodale et al., 2016; Misseldine et al., 2021; Ohya et al., 2015; Vescovi & Goodale, 2015) (see Appendix B6). Across studies, distances ranging between 10 and 50 m were used to assess sprint performance qualities.

Elite athletes had greater maximal sprinting speeds (7.96 ± 0.26 vs. 7.53 ± 0.27 $m \cdot s^{-1}$, ES = 1.64) and faster 40-m sprint times (5.63 ± 0.07 vs. 5.79 ± 0.17 seconds, ES = -1.50) compared with nonelite, whereas 10-m sprint time was similar between elite and nonelite athletes. At the elite level, backs had greater maximal sprinting speeds (8.06 ± 0.20 vs. 7.86 ± 0.25 $m \cdot s^{-1}$, ES = 0.89) and faster 10-m (1.81 ± 0.03 vs. 1.84 ± 0.04 s, ES = -0.85) and 40-m sprint times (5.60

± 0.14 vs. 5.72 ± 0.12 s, ES = -0.92). Sprint times over 30 and 50 m were similar between backs and forwards (Table 5).

Power. A total of nine studies reported the power abilities of athletes or proxy measures of power (e.g., distance and velocity) (Agar-Newman et al., 2017; Clarke et al., 2015c; Clarke et al., 2017b; Del Coso et al., 2013; Gathercole et al., 2015; Goodale et al., 2016; Leite et al., 2016; Ohya et al., 2015; Valenzuela et al., 2018) (see Appendix B7). A variety of horizontal (Agar-Newman et al., 2017; Goodale et al., 2016) and vertical jumps (Clarke et al., 2015c; Clarke et al., 2017b; Del Coso et al., 2013; Gathercole et al., 2015; Ohya et al., 2015) as well as cyclical movements (Valenzuela et al., 2018) was used to assess the lower-body power abilities of athletes, whereas the bench press exercise was used as an indicator of upper-body power (Leite et al., 2016).

During a countermovement jump (CMJ), elite athletes produced greater relative mean power (39 ± 4 vs. 33 ± 7 $W \cdot kg^{-1}$, ES = 1.08), relative peak power (60 ± 4 vs. 56 ± 10 $W \cdot kg^{-1}$, ES = 0.69), and peak velocity (3.2 ± 0.2 vs. 3.0 ± 0.3 $m \cdot s^{-1}$, ES = 0.80) compared with nonelite. Vertical jump height was similar between elite and nonelite athletes. In elite athletes, standing long jump and standing triple jump distance as well as CMJ and squat jump height were similar between backs and forwards (Table 5).

Strength. Strength qualities were reported in three studies (Agar-Newman et al., 2017; Goodale et al., 2016; Leite et al., 2016) (see Appendix B8). Across the studies, absolute and relative maximum strength (1-repetition maximum [1RM]) were assessed for lower (front squat, power clean) (Agar-Newman et al., 2017; Goodale et al., 2016) and upper (bench press, neutral grip pull-up) body (Agar-Newman et al., 2017; Goodale et al., 2016; Leite et al., 2016).

In the bench press exercise, elite athletes displayed greater absolute 1RM (65.2 ± 3.3 vs. 40.3 ± 7.3 kg, ES = 6.19) compared with nonelite. At the elite level, backs had lower absolute 1RM in neutral grip pull-up (78.1 ± 6.7 vs. 86.3 ± 5.2 kg, ES = -1.34), in bench press (61.8 ± 7.1 vs. 68.8 ± 7.1 kg, ES = -0.99), and in power clean (68.2 ± 6.2 vs. 73.5 ± 4.5 kg, ES = -0.97) compared with forwards. Absolute and relative 1RM in the front squat and relative 1RM in the power clean, bench press, and neutral grip pull-up were similar between backs and forwards (Table 5).

Aerobic Capacities. Seven studies addressed the aerobic capacities of athletes (Agar-Newman et al., 2017; Clarke et al., 2015a; Clarke et al., 2017b; Clarke et al., 2014; Goodale et al., 2016; Suarez-Arrones et al., 2012; Vescovi & Goodale, 2015) (see Appendix B9). Across studies, a range of field-based and laboratory tests were used, such as the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) (Clarke et al., 2017b; Clarke et al., 2014; Vescovi & Goodale, 2015), 1600-m time trial (Agar-Newman et al., 2017; Goodale et al., 2016), critical velocity test (Clarke et al., 2014), and $\dot{V}O2$ max incremental treadmill test (Clarke et al., 2015a; Clarke et al., 2014; Suarez-Arrones et al., 2012). During the Yo-Yo IR1 test, elite athletes covered greater distance compared with nonelite (1300 ± 219 vs. 955 ± 136 m, ES = 1.82). In elite athletes, 1600-m running time was similar between backs and forwards (Table 5).

Table 5. Summary of physical qualities of female Rugby Sevens athletes.

Competition Level	Speed			Power				Strength	Aerobic
	0-10 m (s)	0-40 m (s)	Max Speed ($m \cdot s^{-1}$)	VJ Height (cm)	CMJ RPP ($W \cdot kg^{-1}$)	CMJ RMP ($W \cdot kg^{-1}$)	CMJ PV ($m \cdot s^{-1}$)	Bench Press 1 RM (kg)	Yo-Yo IR1 (m)
Elite *(n)*	1.81 ± 0.03 (58)	5.63 ± 0.07 (58)	7.96 ± 0.26 (86)	49.6 ± 3.8 (11)	60 ± 4 (24)	39 ± 4 (12)	3.2 ± 0.2 (12)	65.2 ± 3.3 (43)	1300 ± 219 (49)
Nonelite *(n)*	1.82 ± 0.06 (22)	5.79 ± 0.17 (22)	7.53 ± 0.27 (35)	47.4 ± 5.5 (22)	56 ± 10 (10)	33 ± 7 (10)	3.0 ± 0.3 (10)	40.3 ± 7.3 (7)	955 ± 136 (35)
ES [95% CI]	-0.25 [-0.74,0.25]	-1.50^{L} [-2.03,-0.94]	1.64^{L} [1.18,2.07]	0.44 [-0.30,1.16]	0.69^{M} [-0.08,1.43]	1.08^{M} [0.15,1.93]	0.80^{M} [-0.10,1.64]	6.19^{X} [4.65,7.53]	1.82^{L} [1.29,2.32]

Playing Position (Elite)	Speed					Power				Strength				Aerobic
	0-10 m (s)	0-30 m (s)	0-40 m (s)	0-50 m (s)	Max Speed ($m \cdot s^{-1}$)	SLJ (m)	STJ (m)	CMJ Height (m)	SJ Height (m)	Front Squat 1 RM ($kg, kg \cdot kg^{-1}$)	Power Clean 1 RM ($kg, kg \cdot kg^{-1}$)	Bench Press 1 RM ($kg, kg \cdot kg^{-1}$)	Pull-up 1 RM ($kg, kg \cdot kg^{-1}$)	1600 m (s)
Backs *(n)*	1.81 ± 0.03 (12)	4.64 ± 0.19 (9)	5.60 ± 0.14 (12)	7.26 ± 0.29 (9)	8.06 ± 0.20 (19)	229 ± 11 (12)	705 ± 32 (12)	38.4 ± 4.2 (10)	33.0 ± 3.5 (10)	82.5 ± 11.3, 1.2 ± 0.2 (8)	68.2 ± 6.2, 1.0 ± 0.1 (8)	61.8 ± 7.1, 0.9 ± 0.1 (11)	78.1 ± 6.7, 1.2 ± 0.1 (12)	390 ± 28 (13)
Forwards *(n)*	1.84 ± 0.04 (11)	4.74 ± 0.11 (9)	5.72 ± 0.12 (11)	7.39 ± 0.16 (9)	7.86 ± 0.25 (16)	228 ± 9 (11)	691 ± 28 (11)	37.5 ± 4.0 (10)	32.9 ± 3.6 (10)	84.5 ± 5.8, 1.1 ± 0.1 (9)	73.5 ± 4.5, 1.0 ± 0.0 (7)	68.8 ± 7.1, 0.9 ± 0.1 (10)	86.3 ± 5.2, 1.2 ± 0.1 (9)	377 ± 25 (10)
ES [95% CI]	-0.85^{M} [-1.68,0.03]	-0.64 [-1.56,0.33]	-0.92^{M} [-1.74,-0.03]	-0.56 [-1.47,0.41]	0.89^{M} [0.18,1.57]	0.10 [-0.72,0.91]	0.46 [-0.38,1.28]	0.22 [-0.67,1.09]	0.03 [-0.85,0.90]	-0.23 [-1.17,0.74], 0.65 [-0.36,1.59]	-0.97^{M} [-1.98,0.16], 0.00 [-1.01,1.01]	-0.99^{M} [-1.85,-0.04], 0.00 [-0.86,0.86]	-1.34^{L} [-2.22,-0.34], 0.00 [-0.86,0.86]	0.49 [-0.37,1.30]

Data are presented as mean ± SD. Pooled based on sample size.

CI = Confidence interval, CMJ = Countermovement jump, ES = Effect size, PV = Peak velocity, RM = Repetition Maximum, RMP = Relative mean power, RPP = Relative peak power, SJ = Squat jump, SLJ = Standing long jump, STJ = Standing triple jump, VJ = Vertical jump, Yo-Yo IR1 = Yo-Yo Intermittent Recovery Test Level 1.

^{T}trivial, ^{S}small, ^{M}moderate, ^{L}large, ^{V}very large, ^{X}extremely large.

Discussion

Across the studies reviewed, most of the research focused on elite female Rugby Sevens athletes playing at an international level, whereas a limited number of studies focused on nonelite athletes. Most of the studies pooled the results of athletes together, without differentiating between backs and forwards. Based on the available data, differences between competition levels and playing positions were observed in match demands, anthropometric characteristics, and physical qualities that can have implications in athlete development, coaching, and training.

International matches had greater running demands, running intensities, a higher number of sprints and accelerations in comparison with national matches but were characterised by lower physiological responses (i.e., lower HRs values). The superior physical qualities of elite female Rugby Sevens athletes are likely to explain these findings. Well-developed aerobic capacities have shown moderate-to-large correlations with on-field running performance in female Rugby Sevens (Clarke et al., 2015a; Clarke et al., 2017b; Clarke et al., 2014; Vescovi & Goodale, 2015). In addition, possessing greater aerobic capacities seems to be advantageous to minimise fatigue and facilitate recovery between repeated high intensity bouts (Ross et al., 2014; Stone & Kilding, 2009; Tomlin & Wenger, 2001). Moderate-to-large correlations have been observed between acceleration abilities (i.e., 10-m time) and match sprint performance in female Rugby Sevens' matches (Clarke et al., 2017b). Furthermore, because female Rugby Sevens athletes repeatedly reach running speeds above 90% of their maximal sprinting speed during matches (Misseldine et al., 2021; Vescovi & Goodale, 2015), superior sprinting abilities possessed by elite athletes likely accounts for and contributes to the increased running demands and performances during international matches.

In international matches, backs demonstrated greater maximal speeds, running intensities, and physiological responses than forwards. Furthermore, although we could not undertake comparisons as no SD values were clearly reported, greater total distance (ES = 0.77, $p \leq 0.05$), number of sprints ($p \leq 0.05$), and sprint distance ($p \leq 0.05$) have been shown to differentiate elite backs to forwards (Malone et al., 2020). The specific positional role of backs to carry the ball in wider areas of the field (Malone et al., 2020), combined with their superior sprinting ability, likely explain these increased running and physiological demands.

By contrast, the total workload of forwards could be underestimated when only considering GPS running load data because this does not account for Rugby-specific demands such as rucking, lineouts, and scrummaging, where the objective is to gain and secure ball possession (Malone et al., 2020). The different physiological responses between backs and forwards during match play further highlight the specific demands of the positional roles that should be addressed in training.

In addition to the running (GPS) and physiological (HR) match demands, considering the specific technical-tactical demands of the game becomes essential to gain a more comprehensive understanding of the overall on-field demands. To date, four studies (Barkell et al., 2016; Barkell et al., 2017; Portillo et al., 2017; Reyneke et al., 2018) have reported information on the technical-tactical demands of female Rugby Sevens matches. However, because all four studies addressed international matches, without differentiating between playing positions, further research is required to investigate the Rugby-specific demands of backs and forwards during international- and national-level matches.

Elite female Rugby Sevens athletes were found to be leaner, taller, and slightly heavier compared with their nonelite counterparts. The increased running demands observed at the international level, along with the greater level of organised training and nutritional support provided to elite-level athletes, may explain some of these differences (Ross et al., 2015d). Furthermore, it is possible that specific anthropometric characteristics could be beneficial for specific technical demands of the game.

At the elite level, body mass discriminated between forwards and backs, with small-to-moderate differences also observed in height and body fat. In Rugby Sevens, forwards are required to engage in scrums and participate in lineouts; as a result, being heavier and taller is likely to be advantageous for performing these tasks successfully (Agar-Newman et al., 2017; Ross et al., 2015d). Whereas, only small differences in body mass were observed between nonelite backs and forwards with no clear difference in height. These findings are based on the results of a single study (Ma et al., 2016); therefore, generalisation across nonelite players is challenging. Another study (Clarke et al., 2017b) found nonelite and junior female Rugby Sevens forwards to be heavier and taller and possess higher skinfolds and greater lean mass compared with backs, agreeing with elite findings. However, given the paucity of data and lack of clear reporting, further research is required to determine whether any positional differences exist in the anthropometric characteristics of nonelite female Rugby Sevens athletes.

Overall, elite female Rugby Sevens athletes were characterised by superior physical qualities compared with nonelite, and differences were observed between playing positions. Greater maximal speeds discriminated elite compared with nonelite athletes; however, unclear differences in acceleration abilities were observed. Although correlated, acceleration and maximal speed represent two distinct components of sprint running (Baker & Nance, 1999;

Buchheit et al., 2014). Therefore, prioritising training interventions which aim at improving the mechanisms associated with maximal speed may be of further benefit for playing at the highest level. During international matches, elite athletes were found to cover ~15 m per sprint (Malone et al., 2020; Suarez-Arrones et al., 2012); however, athletes are also required to sprint over 30 m at times (Malone et al., 2020; Suarez-Arrones et al., 2012), indicating that working on maximal speed and speed-maintenance abilities is also important. Elite backs attained higher maximal speeds and faster times over 10 and 40 m than forwards. As previously discussed, superior sprinting abilities would be advantageous for backs given their positional role.

In collision sports, assessing sprint momentum (sprint velocity multiplied by body mass) in addition to sprinting speed can interest practitioners (Baker & Newton, 2008; Barr et al., 2014). In fact, in male Rugby Sevens, 10-m sprint momentum was found to be a greater indicator of on-field performance in contact situations (e.g., defensive rucks and dominant tackles) than 10-m sprinting time alone (Ross et al., 2015c). In the only study comparing sprint momentum between elite and nonelite female Rugby Sevens athletes, no differences were observed between groups (Clarke et al., 2017b). However, given the differences in body mass and sprinting abilities highlighted in this review, it is likely that greater sprint momentum would characterise elite compared with nonelite athletes in the presence of a larger sample size. In elite female Rugby Sevens athletes, greater sprinting momentum differentiated forwards compared with backs (ES = 1.33–1.53) (Agar-Newman et al., 2017), despite their lower sprinting abilities, indicating that both sprinting qualities and body mass could be useful metrics to consider when assessing athletic qualities in Rugby Sevens.

Comparisons between jumping abilities highlighted that elite female Rugby Sevens athletes are able to express greater relative power and produce higher velocities during the CMJ. Despite differences in sprinting abilities, similar vertical and horizontal jumping abilities were observed between playing positions at the elite level. In female Rugby athletes (both Sevens and Fifteens), horizontal jumping ability has been found to be largely to very largely correlated with measures of sprint running (Agar-Newman & Klimstra, 2015). However, when grouping athletes based on sprint performance, the relationship between horizontal jumping ability and sprinting speed decreases in faster athletes (Agar-Newman & Klimstra, 2015). These findings suggest that horizontal jump tests may be a better proxy measure of sprint performance in lower-level athletes, whereas more detailed mechanistic performance tests may be required for assessing faster athletes (Agar-Newman & Klimstra, 2015).

Greater absolute upper-body (bench press) strength also discriminated between elite and nonelite athletes. One study also demonstrated that superior upper-body strength discriminated between athletes who played high minutes and low minutes across a full international season within a squad of elite female Sevens athletes (Goodale et al., 2016). Given the contact nature of Rugby Sevens, it is clear that possessing well-developed upper-body strength qualities is advantageous to perform a number of rugby-specific tasks, such as tackling, rucking, scrummaging, fending, and wrestling (Goodale et al., 2016; Ross et al., 2014) as well as physical resiliency to tolerate the physical stress associated with collisions (Goodale et al., 2016). No information on the lower-body strength abilities of nonelite female Rugby Sevens athletes was found, so it is unknown whether differences exist in the lower-body maximum strength between playing levels. Our review showed that greater absolute upper-body (bench press and pull-up) strength was observed in elite forwards compared with backs; however, when strength was expressed in relation to body mass, differences between playing positions were no longer present. Indeed, absolute upper-body strength rather than relative strength might be advantageous for forwards during match play in scrum, lineout, and ruck situations

(Agar-Newman et al., 2017; Goodale et al., 2016). Contrasting results were observed in lower-body maximal strength between playing positions in elite athletes. The current results are based on data reported in single study using a relatively small sample size (Agar-Newman et al., 2017), warranting further research in lower-body strength qualities between backs and forwards to inform practice.

Superior aerobic capacities were observed in elite than nonelite athletes. Furthermore, better aerobic capacities were found to differentiate between athletes who played high and low minutes during a full international season (Goodale et al., 2016). Given the HR responses and high physiological demands (i.e., majority of the match >80% of HRmax) observed during matches, a well-developed aerobic system is advantageous for tolerating the demands and optimising performance in Rugby Sevens. As previously discussed, possessing a well-developed aerobic system has been shown to be beneficial for on-field running performance in female Rugby Sevens athletes (Clarke et al., 2015a; Clarke et al., 2017b; Clarke et al., 2014; Vescovi & Goodale, 2015) and to minimise fatigue during the match play (Ross et al., 2014; Stone & Kilding, 2009; Tomlin & Wenger, 2001). Furthermore, given the specific format of Rugby Sevens with multiple matches per day, well-developed aerobic capacities could be advantageous to facilitate recovery between matches (Ross et al., 2014; Stone & Kilding, 2009; Tomlin & Wenger, 2001). Despite the differences in the running demands and positional roles, similar aerobic capacities were observed between playing positions, thus suggesting the importance of well-developed aerobic capacities for performance for both backs and forwards.

It is important to highlight some limitations inherent to this review. No comparisons between match demands and physical qualities of nonelite backs and forwards were possible because of a lack of the literature. A variety of tests, protocols, and equipment were used to assess specific match, anthropometric, and physical metrics, which further reduced the possible comparisons between groups. Standardisation of tests and protocols across research groups and governing bodies would allow for better comparisons and a greater understanding of female Rugby Sevens. Furthermore, matches can last more than 14 minutes due to the specific laws of the game. A limited number of research studies report or account for the exact playing time when coding match data, which would provide a more accurate representation of the on-field demands.

None of the studies reviewed addressed sample size considerations. The number of participants across most of the studies (median, x = 22) reflects the average number of athletes comprising a Rugby Sevens team. However, because of the relatively small sample size, the results may not represent the female Rugby Sevens population as a whole. Because multiple studies addressed elite athletes from specific countries, the same athletes might have been sampled multiple times and bias the current review findings. Furthermore, despite the biphasic responses of oestrogen and progesterone across the menstrual cycle and their potential effects on different body systems and functions (Constantini et al., 2005) and the increasing number of athletes using oral contraceptive (Rechichi et al., 2009), no studies reported information regarding the type (menstrual or contraceptive) and phase (high or low hormones) of the cycle of participants at the time of testing.

To describe the percentage time spent at different physiological intensities (HR zones), data from slightly different HR categories were pooled together. The speed zones across studies were not consistent, thus making comparisons between studies challenging. For example, 3.5 (Goodale et al., 2017), 4.4 (Malone et al., 2020; Vescovi & Goodale, 2015), or 5.0 $m \cdot s^{-1}$ (Del Coso et al., 2013; Portillo et al., 2014; Suarez-Arrones et al., 2012) have been used as the threshold for high-intensity running although findings support that 3.5 $m \cdot s^{-1}$ is a more appropriate threshold in female Rugby Sevens athletes than 5.0 $m \cdot s^{-1}$ to avoid underestimating high-intensity workloads (Clarke et al., 2015a). Similarly, despite 5.5 $m \cdot s^{-1}$ being used as a threshold for quantifying sprinting (Malone et al., 2020; Misseldine et al., 2021; Portillo et al., 2014; Suarez-Arrones et al., 2012), 4.7 $m \cdot s^{-1}$ has been suggested as a more specific threshold adjusted for female Rugby Sevens athletes (Misseldine et al., 2021). That said, given the average maximal speed values registered during female Rugby Sevens matches range from 7.0 to 7.3 $m \cdot s^{-1}$ (Table 2) the most appropriate threshold to capture the sprinting demands of games is debatable.

Practical applications

This systematic review provides useful information for coaches and strength and conditioning practitioners regarding the match demands, anthropometric characteristics, and physical qualities of the female Rugby Sevens athlete. Female Sevens athletes aiming to compete at the highest level should focus on developing maximal speed, lower-body power, upper-body strength, aerobic capacity, and lean muscle mass with relatively low amounts of body fat. At the elite level, given the specific positional roles, well-developed acceleration and maximal speed abilities would be advantageous for backs, whereas forwards would benefit by possessing well-developed upper-body strength and greater body mass. The specific requirements of female Rugby Sevens athletes competing at different playing levels and playing positions must be taken into account when developing training programmes to maximise athletes' preparation.

Match performance and physical qualities

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Chapter 3 - The associations between physical-test performance and match performance in women's Rugby Sevens players

Introduction

Women's Rugby Sevens is an intermittent, field-based team sport characterised by high-intensity activities and collisions (Sella et al., 2019). Two teams of seven players contest matches over two 7-min halves in a tournament format over 2-3 days. Similar to other team sports, a combination of technical, tactical, and physical factors determines success in Rugby Sevens (Ross et al., 2014). While some of these factors (e.g., tactical awareness, decision making, and passing accuracy) are independent of physical measures, evaluating the relationships between physical-test and match performance could provide helpful information to implement specific training programmes for enhancing match performance (Ross et al., 2014) and refining athlete evaluation.

In a previous study on women's Rugby Sevens across different playing levels, performance in various physical tests (10-m acceleration, 40-m sprint, Yo-Yo IR1) to large correlations with some match-running activities, including total distance, distance covered >5 $m \cdot s^{-1}$, and maximal speed (Clarke et al., 2017b). However, several other measures of match running from the women's Rugby Sevens literature such as number of sprints and accelerations (Goodale et al., 2017; Misseldine et al., 2021) were not included in this study; match actions were also not included. In provincial-representative and international-level men's Rugby Sevens players, moderate to large correlations were observed between numerous physical-test measures and various match actions (e.g., tries scored) (Ross et al., 2015c), but no studies have tested the relationships between physical-test measures and match actions in women's Rugby Sevens.

Therefore, in this study, we explored the associations of a range of physical-test measures with various match-running and match-action measures in women's Rugby Sevens players.

Methods

Participants

Thirty women's Rugby Sevens players (age: 22 ± 5 y, height: 1.68 ± 0.05 m, mass: 69 ± 7 kg) representing five different New Zealand Provincial Union teams participated in the study. Each participant provided written informed consent and ethical approval was granted from the University of Waikato Human Research Ethics Committee (HREC#2018-10).

Study design

The association between physical-test performance and match performance in women's Rugby Sevens players was examined using a descriptive correlation design. Participants performed a battery of physical tests within the two weeks before a two-day tournament. Match-running and match-action data were collected as measures of athlete performance using GPS units and video analysis. All tests employed are commonly used in Rugby (Goodale et al., 2016; Ross et al., 2015c; Sella et al., 2021b).

Acceleration and maximal speed

Acceleration and maximal speed abilities were assessed over a 40-m sprint on an outdoor artificial turf. Single beam timing lights (Brower Timing System, Utah, USA) were positioned at 0, 10, 30, and 40 m. The first gate was set at a 0.5 m height, while the remaining were set at 0.75 m. Prior to performing the sprints, participants completed a 10-minute standardised warm up comprising of jogging, dynamic stretches, running drills, and three stride-outs at increasing intensity. Participants started each sprint in a standing split position 0.5 m behind the first gate and were instructed to "run as fast as possible" past the last gate. Each participant performed two maximal effort sprints, separated by three minutes of passive rest. Sprint time was measured to the nearest 0.01 second. The fastest 10-m, 30-m, 40-m, and 30-40 m times were transformed into average running speeds and used for analysis. The speed over 10 m was used as an indicator of acceleration ability, while 30-m, 40-m, and 30-40 m speeds were used as measures of maximal speed abilities. The re-test reliability (intraclass correlation coefficient, ICC) for 10-m, 30-m, and 40-m sprint times in women's Rugby Sevens players using similar equipment was 0.90, 0.95, and 0.96 (Goodale et al., 2016).

Fitness

The 1.2 km shuttle run test, also known as the Bronco test (Sella et al., 2021b), was used as a measure of fitness. The test was performed outdoors, on artificial turf, in running shoes. The protocol consists of a continuous 20, 40, 60 m straight shuttle run, completed five times at maximal intensity (i.e., 20 m and back, 40 m and back, 60 m and back) (Kelly & Wood, 2013). Total running time was recorded with a stopwatch. Average running speed was calculated from total time and used for analysis. The ICC for Bronco time was 0.99 in men's and women's team-sport players combined (Brew & Kelly, 2014).

Countermovement jump

Bodyweight countermovement jumps (CMJs) were assessed using dual-axis force plates (PASPORT force plate, PASCO, California, USA) and analysed using a custom-made software (Weightroom, HPSNZ, Auckland, New Zealand) sampling at 100 Hz. Participants started from an upright standing position with their hands-on hips and were instructed to "bend their knees to a self-selected depth and to jump as high as possible". Two warm up trials were given, followed by two sets of three jumps separated by two minutes rest. The best jump height (calculated from flight time) recorded by each athlete was included in the analysis. The re-test reliability of the best jump height out of three countermovement jumps was 0.97 (ICC) and 3.6% (typical error) in women's Soccer players (Pardos-Mainer et al., 2019).

Maximal strength

Back squat and bench press exercises were used to evaluate lower-body and upper-body maximal strength. For the back squat, athletes started from a standing position and were instructed to "lower until the thighs are parallel to the floor and then come up in the starting position". A miss was recorded if participants failed to meet the proper depth or successfully come up in a straight position. For the bench press, athletes started with the arms fully straight, and were instructed to "lower the bar to the chest and press all the way up" while keeping the glutes in contact with the bench. If an athlete bounced the bar on the chest or failed to press the bar all the way up to a fully extended arms position, a fail was given. Each participant completed two warm up sets at sub-maximal intensities. Thereafter, participants were given three attempts to reach their 2-3 repetition maximum (RM) in each lift, with three minutes rest between attempts. One repetition maximum (1RM) from the lifts was calculated using the formula of Mayhew et al. (Mayhew et al., 1992). ICCs for 1RM testing were ≥0.97 in women's team-sport players (Comfort & McMahon, 2015).

Match performance

Match-running and match-action data were collected during the New Zealand National Rugby Sevens tournament, a two-day tournament between the New Zealand Provincial Unions where each team competes in five to six matches. Match data were considered for players that completed at least a full 7-minute half of a match; therefore, resulting in 1 to 6 files for each player and a total of 119 files included in the analysis (6 players = 1 match, 2 players = 2 matches, 2 players = 3 matches, 5 players = 4 matches, 7 players = 5 matches, 8 players = 6 matches).

Match running

Match running was measured using GPS units (VX Sport 220, Visuallex Sport International, Wellington, New Zealand) sampling at 10 Hz. The validity and reliability of devices with a similar sampling rate have been investigated previously (Castellano et al., 2011; Johnston et al., 2014). Each athlete wore the same GPS unit in every match in a fitted vest under the playing jersey. Data were downloaded and analysed post-tournament using the manufacturer's software (VX View software, Sport International, Wellington, New Zealand). Match files were trimmed to include only the time players were on the field. The variables analysed were based on previous women's Rugby Sevens research (Clarke et al., 2015a; Clarke et al., 2017b; Misseldine et al., 2021) and were described as the frequency of efforts or cumulative distance covered in different speed zones (see Table 6). Sprints were defined as running efforts that required an increase of $\geq$0.70 m·s^{-1} within a second and that reached $\geq$2.8 m·s^{-1} ("VX Sport Metric Glossary," 2021). High-intensity accelerations and decelerations represented the the total number of accelerations and decelerations performed $\geq$2.0 m·s^{-2}.

Match actions

The first author coded match actions using video analysis. The match actions included in the analysis and their operational definitions are presented in Table 7. These measures were chosen to represent different areas of the game in agreement with previous Rugby Sevens studies (Ross et al., 2015b; Ross et al., 2015c). Intra-rater reliability for the analysis was evaluated by re-analysing 10 random matches four weeks apart and calculating the percentage error as described by Hughes et al. (Hughes et al., 2002). Errors observed for all match activities were within the 5% error limit, which was deemed acceptable.

Table 6. Match-performance variables predicted from mixed models without a physical-test predictor.

		Standard deviations[b]		
	Mean[a]	Within-player	Between-player	Observed in matches
Match running				
Match maximal speed ($m·s^{-1}$)	7.4	± 8%	± 6%	± 10%
Distance >7.5 $m·s^{-1}$ (m)	2	×/÷ 3.8	×/÷ 1.96	×/÷ 4.4
Distance >5.5 $m·s^{-1}$ (m)	76	×/÷ 1.55	×/÷ 1.36	×/÷ 1.71
Distance >5.0 $m·s^{-1}$ (m)	113	×/÷ 1.42	± 23%	×/÷ 1.50
Distance >4.7 $m·s^{-1}$ (m)	145	×/÷ 1.34	± 18%	×/÷ 1.40
Distance 5.0-7.5 $m·s^{-1}$ (m)	108	×/÷ 1.41	± 20%	×/÷ 1.48
Distance >3.5 $m·s^{-1}$ (m)	347	± 18%	± 15%	± 24%
Distance 3.5-5.0 $m·s^{-1}$ (m)	233	± 22%	± 23%	×/÷ 1.33
Total distance (m)	1123	± 8%	± 7%	± 11%
Sprints	28	± 13%	± 9%	± 16%
Accelerations	40	± 13%	± 12%	± 18%
Decelerations	19	± 22%	± 13%	± 26%
High-intensity accelerations	34	± 15%	± 15%	± 21%
High-intensity decelerations	13	± 25%	± 18%	×/÷ 1.32
Match actions				
Tries	0.30	×/÷ 4.7	×/÷ 1.89	×/÷ 5.3
Line breaks	0.50	×/÷ 3.0	×/÷ 2.1	×/÷ 3.8
Work rate	4.91	×/÷ 1.53	×/÷ 1.34	×/÷ 1.68
Carries	0.85	×/÷ 3.0	×/÷ 1.52	×/÷ 3.2
Tackle breaks	0.40	×/÷ 3.9	×/÷ 2.6	×/÷ 5.3
Effective attacking rucks	0.25	×/÷ 5.6	×/÷ 1.52	×/÷ 5.9
Handling errors	0.38	×/÷ 5.7	± 0%	×/÷ 5.7
Tackles	2.00	×/÷ 1.84	×/÷ 1.34	×/÷ 2.0
Missed tackles	0.85	×/÷ 2.9	± 23%	×/÷ 3.0
Turnovers won	0.30	×/÷ 5.3	×/÷ 1.77	×/÷ 5.9

[a]Uncertainty (×/÷90% CL): for match running, 1.02-1.41; for match actions, 1.12-1.45.
[b]Derived from the mixed model: within-player is the residual, between-player is from the player identity, and the observed is their combination (via variances). Values ≥30% are shown as factors. Uncertainty (×/÷90% CL): for match running, 1.01-1.43; for match actions, 1.06-1.94.

Table 7. Operational definitions of match actions included in the analysis.

Match action	Description
Attack	
Tries	Count of tries scored by the player
Line breaks	Count of times the ball carrier breaks the defensive line
Carries	Count of times a player carries the ball into contact
Tackle breaks	Count of tackles evaded by the ball carrier
Effective attacking rucks	Count of attacking rucks in which the player successfully clears the opposition making the ball available to play
Handling errors	Sum of knock-ons, passes to ground, and dropped balls by the player
Defence	
Tackles	Count of tackles completed by the player
Missed tackles	Count of tackles attempted and missed by the player
Turnovers won	Count of times a player turns over the ball into an offensive situation from a defensive play
Combined	
Work rate	Sum of tries, line breaks, carries, tackle breaks, effective attacking rucks, tackles, and turnovers won

Statistical analysis

Data were analysed with the Statistical Analysis System (University Edition of SAS Studio, version 9.4, SAS Institute, Cary NC). Pearson correlations between each pair of physical-test variables were derived as a correlation matrix, and the variables were ordered to reveal clusters of similar variables (higher correlations within clusters than between clusters). The same analyses were performed for match-performance variables.

For measures of match performance that were counts or proportional to counts, the association between each physical characteristic and the measure was analysed with Poisson regression using the generalised linear mixed model procedure (Proc Glimmix) with a log link. This procedure allows modelling of count variables and accounting for repeated match-performance measurements on the same player. Each physical characteristic (predictor) presented in Table 3 was entered in the model separately as a numeric linear fixed effect to allow estimation of the effect of a two standard-deviation (2-SD) difference in the predictor on match performance (Hopkins et al., 2009; Ross et al., 2015c). The number of matches played by each athlete in the tournament, and the log of total match time (as a fraction of a 14-min match) for each player in each match, were included as numeric linear fixed effects to estimate the tournament trend of the dependent variable and to adjust each player's score to a mean match time, respectively. Random effects in the model were nominal variables representing player identity (to adjust for between-player differences in means), match identity (to adjust for between-match differences in means), and team identity (to adjust for between-team differences in means). Over- or under-dispersion of the residual variance was estimated, which was particularly important for measures representing counts of running bouts. Distance covered >7.5 $m \cdot s^{-1}$ produced an unrealistic estimate of over-dispersion, so it was analysed with the general linear mixed-model procedure (Proc Mixed) after log transformation, with values of 0 first set to half of the smallest non-zero value. The fixed and random effects were the same as for the Poisson-regression model. The same general linear mixed model was used to analyse the only measure of match performance that was not a count or count of bouts (maximal speed), which was also log transformed. Estimates for the tournament trend were also obtained from the generalised and the general linear mixed models without a physical-test predictor.

The qualitative magnitude of the effects was assessed using standardisation, with threshold values for small, moderate, large, very large, and extremely large calculated as 0.2, 0.6, 1.2, 2.0, and 4.0 of the observed between-player SD (Hopkins et al., 2009), derived by combining the variances represented by player identity (true differences between players) and the residual (within-player between match variance), and adjusted for small samples (Hopkins, 2019a). Effect magnitudes for tries were also determined as the factors associated with an increase in the number of tries scored by a team to give the team 1, 3, 5, 7, and 9 extra wins every 10 matches, representing small, moderate, large, very large, and extremely large effects (Hopkins et al., 2009). The factors were estimated using a simulation based on points scored by all the teams in the tournament. There was a mean of 2.7 tries scored per team per match (5 points per try), with a 52% probability of converting a try (2 points per conversion). There were no field goals or penalties. We assumed a team had 10 try-scoring opportunities in a match on the basis of our experience. The resulting magnitude thresholds were not sensitive to the number of opportunities. An opponent team was assumed to have an unchanging probability of scoring a try per opportunity equal to 27% (2.7 tries per 10 opportunities). The factor associated with a given increase in wins per 10 matches allowed for the affected team to have a try-scoring probability per trial <27% before the factor was applied (probability = 0.27/√factor), but it increased to >27% after the factor was applied (probability = 0.27*√factor). Simulations were performed to generate scores in 10,000 matches for the two teams before and after the factor was applied, then wins were scored as 1 and loss or draw as 0. The factors giving 1, 3, 5, 7, and 9 extra wins every 10 matches were found by "trial and error". Corresponding magnitude thresholds for factor increase/decrease were 1.20/0.83, 1.75/0.57, 2.60/0.38, 4.10/0.24, and 11.0/0.09. The spreadsheet of simulations is available on request.

Physical-test scores are shown as means and standard deviations (SDs). Means of the dependent variables are shown as the back-transformed least-squares means with SDs in back-transformed ± percent units (when <30%) or ×/÷ factor units (when >30%) derived from a model without a physical-test predictor. Effects are presented in percent units with uncertainty expressed as ±90% compatibility (or confidence) limits (CL), when either the effect or the ±90% CL were <30%; otherwise, factor effects with ×/÷90% CL are reported. Decisions about magnitudes accounting for sampling uncertainty were based on one-sided interval hypothesis tests, according to which a hypothesis of a given magnitude (substantial, non-substantial) is rejected if the 90% compatibility interval falls outside that magnitude (Hopkins, 2020; Hopkins, 2022). P-values for the tests were therefore the areas of the sampling t-distribution of the effect falling in the hypothesised magnitude, with the distribution centred on the observed effect. Hypotheses of inferiority (substantial negative) and superiority (substantial positive) were rejected if their respective p-values ($p_–$ and p_+) were <0.05; rejection of both hypotheses represents a decisively trivial effect in equivalence testing. The hypothesis of non-inferiority (non-substantial-negative) or non-superiority (non-substantial-positive) was rejected if its p-value ($p_{N–}$=1–$p_–$ or p_{N+}=1–p_+) was <0.05, representing a decisively substantial effect in minimal-effects testing. A complementary Bayesian interpretation of sampling uncertainty was also provided, when at least one substantial hypotheses was rejected: the p-value for the other hypothesis is the posterior probability of a substantial true magnitude of the effect in a Bayesian analysis with a non-informative prior (Hopkins, 2019b, 2020; Hopkins, 2022), and it was interpreted qualitatively using the following scale: >0.25, possibly; >0.75, likely; >0.95, very likely; and >0.995, most likely (Hopkins et al., 2009). The probability of a trivial true magnitude (1–$p_–$–p_+) was also interpreted with the same scale. Possible or likely magnitudes are categorised as some evidence for those magnitudes; very likely and most likely are categorised as good evidence. Probabilities were not interpreted for unclear effects: those with inadequate precision at the 90% level, defined by failure to reject both substantial hypotheses ($p_–$>0.05 and p_+>0.05). Effects on magnitudes and probabilities of a weakly informative normally distributed prior centred on the nil effect and excluding extremely large effects at the 90% level were also investigated (Greenland, 2006; Hopkins, 2019b).

Effects with adequate precision at the 99% level ($p_–$<0.005 or p_+<0.005) are highlighted in bold in tables, since these represent stronger evidence against substantial hypotheses than the 90% level and therefore incur lower inflation of error with multiple hypothesis tests. For practitioners considering implementation of a treatment based on an effect in this study (e.g., training to improve try scoring by increasing jump height), the effect needs only a modest chance of benefit (at least possibly increased try scoring, $p_{+}>0.25$) but a low risk of harm (most unlikely impaired try scoring, $p_{-}<0.005$). Substantial effects highlighted in bold therefore represent potentially implementable effects. However, it is only for effects on tries scored assessed via match winning that the outcomes have direct relevance to benefit and harm (winning and losing matches); these effects were therefore also deemed potentially implementable when the chance of benefit outweighed an otherwise unacceptable risk of harm (the odds ratio of benefit to harm >66.3) (Hopkins & Batterham, 2016). For these effects, the potential for benefit and harm was also investigated for realistic changes in physical-tests measures (less than 2 SD).

Results

Physical tests and match performance

Mean values and between-subjects SD of physical-test scores are presented in Table 8, while means of the dependent variables with the within-player, between-player, and observed SD are reported in Table 6. The within-player SD represents the match-to-match within-player variation, the between-player SD is the true difference between players, and the observed SD is the combination of the within- and between-player SDs representing the observed between-player SD in a typical match.

Table 8. Characteristics of the players in the physical tests. Data are mean[a] ± SD[b] (sample size).

10-m average speed ($m \cdot s^{-1}$)	5.30 ± 0.18 (16)
30-m average speed ($m \cdot s^{-1}$)	6.47 ± 0.23 (16)
40-m average speed ($m \cdot s^{-1}$)	6.72 ± 0.28 (16)
Maximal speed ($m \cdot s^{-1}$)	7.66 ± 0.49 (16)
Bronco average speed ($m \cdot s^{-1}$)	3.51 ± 0.27 (16)
Bench press 1RM (kg)	59 ± 10 (28)
Back squat 1RM (kg)	90 ± 15 (26)
CMJ height (cm)	32.2 ± 4.1 (20)

CMJ = Countermovement jump, 1RM = One repetition maximum.

[a]Uncertainty (±90% CL): 1.5-5.7%.
[b]Uncertainty (×/÷90% CL): 1.26-1.36.

Correlations within and between groups of variables

Correlation matrices for the physical-test and match measures are shown in the Appendix (Tables C1-C4), where clusters of variables have been identified as those with correlations ≥0.50 within clusters and <0.50 between clusters. The clusters of variables in each correlation matrix are delineated in the effects table (Table 9), because correlated variables were expected to have similar effects.

There were two overlapping clusters of physical-test variables for maximal-speed running measures, one with 10-m speed and one with Bronco; there was also a well-defined cluster for strength measures (Appendix, Table C1). The correlation matrix for measures of match running revealed four clusters, representing running at high intensities, running at lower intensities (with distance >5.5 $m \cdot s^{-1}$ in both clusters), total running (with sprinting, accelerations, and decelerations contributing to this concept), and high-intensity changes in speed (Appendix, Table C2). Fewer and less well-defined clusters of variables were found for match actions, with a cluster for tries and line breaks, and a cluster (with one correlation of 0.47) for work rate, carries, and tackle breaks (Appendix, Table C3). No clusters contained match-running and match-action variables, but correlations of match running with match actions (Appendix, Table C4) revealed similar magnitudes within the running and action clusters; in particular, tries and line breaks had negative correlations with measures of total running and positive correlations with high-intensity running.

Effects of physical-test scores on match performance

The effects of a 2-SD difference in physical-test scores on match running and match actions are presented in Table 9. Compatibility intervals and Bayesian probabilities are shown for a minimally informative prior, since appreciable shrinkage occurred with the weakly informative prior for only one effect; jump height on tries scored. In this instance, the factor effect reduced to 3.1, 90% compatibility limits ×/÷2.6, but the magnitude remained large, very likely substantial, and potentially implementable with the odds-ratio assessment of benefit and harm defined by thresholds for match winning.

Match running

Large positive effects were observed for jump height on match maximal speed and distance covered at high intensity, and for acceleration on match maximal speed, where the effects had sufficient precision for the true magnitudes to be very likely or most likely substantial. Acceleration, speed, Bronco, and strength scores displayed consistent moderate positive effects on distance covered at high intensity during matches, with some effects showing sufficient precision for the true magnitudes to be very likely substantial. Moderate positive effects where precision was sufficient for the true magnitude to be very likely substantial were also evident for 30-m speed on match maximal speed, for jump height on distance >7.5 m·s^{-1}, and for Bronco on match total distance, decelerations, and high-intensity decelerations.

Measures where the effects had adequate precision but were only likely substantial included small and moderate positive effects for speed, Bronco, and back squat on match maximal speed, and for speed and Bronco on match distance covered >7.5 m·s^{-1} and on some measures of total running. In contrast, small to moderate negative effects were observed for strength and jump height on some variables contributing to total match running and high intensity changes in speed. Precision was consistently inadequate for speed on match distance 3.5-5.0 m·s^{-1}, accelerations, high-intensity accelerations, high-intensity decelerations, and for strength and jump height on match decelerations and high-intensity decelerations.

Match actions

Moderate and small positive effects were observed for jump height and back squat on tries scored when assessed using standardisation, with adequate precision at the 90% and 99% levels respectively; both were likely substantial. Greater positive effects characterised the same predictors for tries scored when assessed via match winning, and the effects became very likely substantial; both effects had adequate precision only at the 90% level, hence the risk of harm was too high ($p_{-}>0.005$) for a conservative assessment of implementability, but they were potentially implementable when considering the odds ratio of benefit to harm (3700 and 4200, respectively). For these predictors, changes as small as 0.25 SD predicted tries scored that were at least possibly beneficial and with negligible risk of harm, but changes of 0.2 SD were unlikely to be beneficial.

A number of predictors had small or moderate positive effects but were only likely or possibly substantial: back squat and jump height on line breaks, work rate, carries, tackle breaks; 10-m speed on line breaks; maximal speed on work rate; Bronco on work rate and carries; and strength on tackles. On the other hand, back squat and jump height displayed small negative effects on turnovers won with adequate precision, but the effect was only possibly or likely substantial. Precision was inadequate for several predictors on various match-action measures, including the observed small positive effects of measures of running speed and bench press on match winning. Changes in measures of running speed and in bench press smaller than 2 SD were either unclear or at least likely trivial.

Tournament trend

When considering the effects obtained without a physical-test predictor, the measures of match total running and high-intensity changes in speed displayed small to moderate negative trends across the tournament, with adequate precision but only possibly or likely substantial magnitudes. The trend for the match measures of high-speed running ranged from small likely reductions through to small possible increases, but three of the six measures had inadequate precision. There was a similar pattern for match actions, with seven of the 11 measures lacking adequate precision. The tournament trends sometimes changed substantially with different physical-test predictors in the model, but overall the trends were similar to those without predictors.

Table 9. Effects of a 2-SD difference in physical characteristics on match running and match actions. Data are percent effects with ±90% compatibility limits, or factor effects with ×/÷90% compatibility limits; the observed magnitude and probability of a substantial true effect are also shown. Horizontal and vertical dashed and solid lines divide the match and physical-test measures into clusters defined by the correlations between measures within and between clusters shown in the Appendix C1-C3.

	10-m speed (m·s^{-1})	40-m speed (m·s^{-1})	Bronco average speed (m·s^{-1})	Bench press 1RM (kg)	Back squat 1RM (kg)	CMJ height (cm)
Match running						
Match maximal speed	12.5, ±7.1 %; **Large** ↑***	7.4, ±6.6 %; Moderate ↑**	8.0, ±6.9 %; Moderate ↑**	3.0, ±4.8 %; Small ↑*^{0}	6.1, ±4.8 %; **Moderate** ↑**	13.6, ±5.9 %; **Large** ↑****
Distance >7.5 m·s^{-1}	2.6, ×/÷2.4; Moderate ↑**	2.0, ×/÷2.3; Small ↑**	2.4, ×/÷2.4; Small ↑**	1.28, ×/÷1.90; Trivial	1.41, ×/÷1.91; Small ↑	3.5, ×/÷2.2; **Moderate** ↑***
Distance >5.5 m·s^{-1}	1.59, ×/÷1.50; Moderate ↑**	1.56, ×/÷1.38; **Moderate** ↑**	1.69, ×/÷1.35; **Moderate** ↑***	1.34, ×/÷1.26; **Small** ↑**	1.44, ×/÷1.26; **Moderate** ↑***	1.95, ×/÷1.22; **Large** ↑****
Distance >5.0 m·s^{-1}	1.42, ×/÷1.35; Moderate ↑**	1.40, ×/÷1.26; **Moderate** ↑***	1.50, ×/÷1.24; **Moderate** ↑***	29, ±23 %; **Moderate** ↑**	1.31, ×/÷1.19; **Moderate** ↑***	1.63, ×/÷1.18; **Large** ↑****
Distance >4.7 m·s^{1}	1.37, ×/÷1.27; Moderate ↑**	1.33, ×/÷1.19; **Moderate** ↑***	1.39, ×/÷1.19; **Moderate** ↑***	17, ±18 %; Small ↑**	17, ±19 %; Small ↑**	1.48, ×/÷1.16; **Large** ↑****
Distance 5.0-7.5 m·s^{-1}	1.34, ×/÷1.32; Moderate ↑**	1.34, ×/÷1.23; **Moderate** ↑**	1.44, ×/÷1.22; **Moderate** ↑***	29, ±21 %; **Moderate** ↑***	1.31, ×/÷1.18; **Moderate** ↑***	1.58, ×/÷1.18; **Large** ↑****
Distance >3.5 m·s^{-1}	10, ±16 %; Small ↑	11, ±11 %; Small ↑**	12, ±11 %; Small ↑**	-8, ±10 %; Small ↓*^{0}	-7, ±11 %; Small ↓	2, ±12 %; Trivial
Distance 3.5-5.0 m·s^{-1}	-1, ±23 %; Trivial	1, ±20 %; Trivial	-1, ±19 %; Trivial	-18, ±12 %; **Moderate** ↓**	-19, ±13 %; **Moderate** ↓***	-19, ±16 %; Moderate ↓**
Total distance	3.4, ±9.2 %; Small ↑	6.4, ±7.1 %; Small ↑**	9.2, ±6.5 %; **Moderate** ↑***	-5.5, ±4.8 %; Small ↓**	-4.5, ±5.2 %; Small ↓**	-1.1, ±7.1 %; Trivial
Sprints	3.3, ±9.3 %; Small ↑	6.1, ±6.7 %; Small ↑**	7.0, ±6.3 %; Small ↑**	-8.9, ±6.3 %; **Moderate** ↓**	-7.4, ±7.2 %; Small ↓**	-2.1, ±6.8 %; Trivial
Accelerations	-2, ±12 %; Trivial	4, ±11 %; Small ↑	10, ±12 %; Small ↑**	-5.7, ±8.1 %; Small ↓*^{0}	-4.9, ±8.9 %; Small ↓	3, ±11 %; Trivial
Decelerations	9, ±15 %; Small ↑	10, ±10 %; Small ↑**	14.6, ±9.2 %; **Moderate** ↑***	-5, ±11 %; Small ↓	-3, ±12 %; Trivial	-1, ±14 %; Trivial
High-intensity accelerations	13, ±19 %; Small ↑	9, ±15 %; Small ↑	11, ±14 %; Small ↑**	-12.3, ±9.0 %; **Moderate** ↓**	-10, ±10 %; Small ↓**	5, ±15 %; Small ↑
High-intensity decelerations	9, ±21 %; Small ↑	8, ±16 %; Small ↑	21, ±12 %; **Moderate** ↑***	-2, ±15 %; Trivial	6, ±16 %; Small ↑	6, ±18 %; Small ↑
Match actions						
Tries	1.3, ×/÷2.8;	1.4, ×/÷2.3;	1.5, ×/÷2.3;	1.55, ×/÷1.92;	2.5, ×/÷2.0;	3.8, ×/÷2.8;
via standardisation	Trivial	Trivial	Trivial	Small ↑*^{0}	**Small** ↑**	Moderate ↑**
via match winning	Small ↑	Small ↑	Small ↑	Small ↑	Moderate ↑***	Large ↑***
Line breaks	2.6, ×/÷2.7; Moderate ↑**	1.2, ×/÷2.1; Trivial	1.0, ×/÷2.2; Trivial	1.37, ×/÷1.86; Small ↑	2.1, ×/÷1.9; Small ↑**	2.8, ×/÷2.3; Moderate ↑**
Work rate	0.99, ×/÷1.38; Trivial	1.21, ×/÷1.30; Small ↑*^{0}	1.31, ×/÷1.28; Small ↑**	16, ±29 %; Small ↑*^{0}	1.37, ×/÷1.28; **Moderate** ↑**	20, ±29 %; Small ↑*^{0}
Carries	1.12, ×/÷1.93; Trivial	1.22, ×/÷1.72; Trivial	1.70, ×/÷1.71; Small ↑**	1.10, ×/÷1.59; Trivial	1.44, ×/÷1.61; Small ↑*^{0}	1.47, ×/÷1.66; Small ↑*^{0}
Tackle breaks	0.7, ×/÷2.6; Small ↓	1.4, ×/÷2.8; Small ↑	1.4, ×/÷2.7; Trivial	1.0, ×/÷2.2; Trivial	1.7, ×/÷2.3; Small ↑*^{0}	2.9, ×/÷3.1; Small ↑**
Effective attacking rucks	0.4, ×/÷4.7; Small ↓	0.5, ×/÷4.5; Small ↓	1.2, ×/÷4.4; Trivial	1.39, ×/÷1.80; Trivial ↑^{0}*	1.19, ×/÷1.90; Trivial	1.1, ×/÷2.2; Trivial
Handling errors	1.3, ×/÷2.4; Trivial	1.5, ×/÷2.1; Small ↑*^{0}	1.8, ×/÷2.1; Small ↑*^{0}	1.03, ×/÷1.73; Trivial	1.20, ×/÷1.76; Trivial	1.73, ×/÷1.92; Small ↑*^{0}
Tackles	0.88, ×/÷1.60; Trivial	1.21, ×/÷1.52; Small ↑	1.30, ×/÷1.56; Small ↑	1.19, ×/÷1.33; Small ↑*^{0}	1.29, ×/÷1.34; Small ↑*	0.86, ×/÷1.44; Small ↓
Missed tackles	0.90, ×/÷1.75; Trivial	0.97, ×/÷1.60; Trivial	1.08, ×/÷1.68; Trivial	1.21, ×/÷1.43; Trivial ↑^{0}*	1.15, ×/÷1.46; Trivial	1.04, ×/÷1.55; Trivial
Turnovers won	1.4, ×/÷2.2; Trivial	1.24, ×/÷1.95; Trivial	1.6, ×/÷2.0; Small ↑*^{0}	0.9, ×/÷2.0; Trivial	0.6, ×/÷2.0; Small ↓*^{0}	0.5, ×/÷2.1; Small ↓**

CMJ = Countermovement jump, 1RM = One repetition maximum. ↑ and ↓ indicate a substantial positive and negative effect, respectively.
With the exception of tries, magnitudes are based on the following scale for standardised changes in the mean using the observed between-player SD (Table 6): <0.2, trivial; 0.2-0.6, small; 0.6-1.2, moderate; 1.2-2.0, large; 2.0-4.0, very large; >4.0 extremely large. Magnitude thresholds for tries are based on simulations of Rugby Sevens matches (see Methods).
Reference-Bayesian likelihoods of substantial change: *possibly; **likely; ***very likely; ****most likely. *** and **** indicate rejection of the non-superiority or non-inferiority hypothesis (p_{N-} or p_{N+} <0.05 and <0.005 respectively).
Reference-Bayesian likelihoods of trivial change: ^{0}possibly; ^{00}likely; ^{000}very likely, ^{0000}most likely.
Likelihoods are not shown for effects with inadequate precision at the 90% level (failure to reject any hypotheses: p>0.05). Magnitudes in **bold** have acceptable precision with 99% compatibility limits.

Discussion

There was good evidence of positive effects of many physical-test measures on match high-intensity running in women's Rugby Sevens athletes. Furthermore, there was some evidence of positive effects of speed and Bronco on match total running and high intensity changes in speed, and of negative effects of maximal strength and jump height on match total running and high intensity changes in speed. There were fewer substantial associations between physical-test measures and match actions: good evidence of positive effects of squat and jump height on tries via standardisation and match winning, and some evidence of positive effects of various predictors on some measures. Small positive effects of measures of running speed and bench press on match winning were observed, but these were unclear. The similarity of the effects observed for some predictors and/or dependent variables reflects the high correlations observed between variables.

Improving back squat and jump height performance could be advantageous for enhancing match winning in provincial-representative women's Rugby Sevens, as the effects for these tests on tries scored were deemed potentially implementable. In Table 9 we have presented the effect of a 2-SD difference in these tests on match performance, representing the difference of moving from a typical low to a typical high value (Hopkins et al., 2009). Achieving such a difference would be unrealistic for athletes already displaying high test values, but a change of 0.25 SD should be achievable for most athletes and was still potentially beneficial. There was less evidence for a beneficial effect (small but unclear) of measures of running speed and bench press on match winning; some changes smaller than 2 SD were unclear and therefore worth further investigation for potential benefit.

The magnitudes of the positive effects (small to large) for match-running measures align with moderate to large correlations (*r* = ~0.3-0.7) between performance in various physical-test and match-running measures reported in the only other comparable study of women's Rugby Sevens players (Clarke et al., 2017b). The authors in that study combined junior, senior, and professional levels, so the correlations within each level would therefore likely be lower. In a study of provincial-representative and international-level men's Rugby Sevens players (Ross et al., 2015c), some of the associations between physical-test measures and match actions were similar to ours in magnitude. A point of difference was that tries scored was moderately correlated with 10-m momentum (sprint velocity multiplied by body mass) and repeated-sprint ability, whereas in our study the measures of running speed in the physical tests had trivial (although unclear) effects on tries scored assessed via standardisation. If this difference is not due simply to sampling variation, then the explanation must reside in differences between either the style of matches or the physiology of male and female players. Unfortunately, jump height and lower-body strength were not measured in the study of men's Rugby Sevens (Ross et al., 2015c), and there have been no other studies of the effects of these test measures on tries or other match actions in Rugby-Sevens.

The small to moderate negative effects of maximal strength and jump height on match measures of total running and high-intensity changes in speed contrast with the moderate to large positive effects of these physical-test measures on match winning. Total running and high-intensity changes in speed are apparently negative match performance indicators, as evidenced by moderately lower total distance and distance covered at 3.5-5.0 $m \cdot s^{-1}$ during wins compared to losses in international women's Rugby Sevens (Goodale et al., 2017). Similarly, in the current study we observed consistently negative correlations between measures of total running and tries scored (Appendix C4).

For most match-running and match-action measures, there was some evidence of small to moderate negative trends over the tournament, likely a result of accumulated fatigue or muscle damage. In line with these findings, professional and state-representative women's Rugby Sevens players displayed small to very large reductions in several match-running measures over a two-day tournament, with greater reductions in state-level players (Clarke et al., 2015c). Both professional and state-representative athletes also reported a large decline in recovery perception, a large increase in perceived soreness, and had large increases in muscle damage (creatine kinase concentration) over the tournament. No information regarding the tournament trend of match actions in women's Rugby Sevens has been reported in other studies.

Due to the fact the physical tests were undertaken within a 14-day period before competition, it is possible that different teams with different training and tapering could have different relationships. To the extent that some of the test measures might be measuring the same underlying construct, the correlations between the measures are similar to reliability correlations, and the measurement error is negligible (in terms of standardisation) only when the correlation is ~0.99 or greater (Hopkins, 2015). On this basis, only the 30-m and 40-m speed are effectively the same measure (Appendix C1), and only one needs to be measured. Measures with lower correlations could either be measuring identical constructs with substantial measurement error or they could be measuring somewhat different constructs. A parsimonious set of physical tests that assess constructs making independent contributions to match performance would be useful for practitioners, but multiple linear regression with a much larger sample size of athletes is needed to identify them. The small sample size herein precluded such an analysis. A similar analysis with more players and matches to predict tries scored with the other match-performance measures might identify a parsimonious set of match measures for predicting match performance of individual athletes. A greater sample size of athletes and matches is also required to get more evidence about the magnitude of the unclear effects observed in this study, especially those on match winning.

Conclusion

Ours is the first study to reveal potentially useful relationships between physical-test measures and match performance in women's Rugby Sevens players. In particular, enhancing players' jump height and back-squat performance could increase the likelihood of match success in women's Rugby Sevens. Valuable future research would include multiple linear regression and experimental studies investigating the effect of changes in physical-test measures on match performance to support the promising utility of these findings for enhancing performance in women's Rugby.

Physical performance enhancement

Sella FS, Beaven CM, Gill ND, McMaster DT, Hébert-Losier K. Low-volume high-intensity interval training programmes in female Rugby Sevens players: A pilot study

Chapter 4 - Low-volume high-intensity interval training programmes in female Rugby Sevens players: A pilot study

Introduction

Rugby Sevens is a field-based team sport in which two teams of seven players compete over two 7-min halves (Sella et al., 2019). Given the intermittent, high-intensity nature of Rugby Sevens, possessing well-developed aerobic and anaerobic fitness qualities seems to be advantageous to perform repeated high-intensity efforts and recover between these bouts throughout matches (Stone & Kilding, 2009). In support of this notion, in female Rugby Sevens, moderate to very large correlations have been observed between performance in the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) and some match-running activities including maximal speed, distance covered >5 $m{\cdot}s^{-1}$, and maximal speed (Clarke et al., 2017b). Furthermore, greater aerobic fitness qualities have been reported to discriminate between athletes who played high minutes and low minutes within a squad of elite female Rugby Sevens athletes (Goodale et al., 2016). Given that Rugby Sevens matches are played in a tournament style format, with five to six matches played over two to three days, superior aerobic fitness qualities may also promote recovery between games (Ross et al., 2014).

A variety of training modalities are used to develop fitness in team sports, such as continuous methods, interval-based approaches, and sport-specific conditioning (e.g., small-sided games) (Stone & Kilding, 2009). Among these, high-intensity interval training (HIIT) is widely employed in Rugby and other team sports (Dobbin et al., 2020; Iaia et al., 2015; Macpherson & Weston, 2015; Robineau et al., 2017). Typically, HIIT consists of repeated short-to long bouts of high-intensity exercise interspersed with recovery periods (Billat, 2001). Similar to the demands of competition in a number of sports, HIIT is intermittent in nature and it can incorporate accelerations, decelerations, and change of directions (Julio et al., 2020). Furthermore, compared to continuous training, HIIT allows the athlete to extend the time spent at higher working intensities (e.g., above maximal aerobic speed, MAS), which appears to be a critical factor for improving aerobic fitness (Dupont et al., 2002).

In a previous study on male amateur Rugby Sevens athletes (Robineau et al., 2017), very likely small and almost likely moderate improvements were observed in the maximal velocity sustained during a graded maximal aerobic running test following short-interval (work:rest = 30 s 100% maximal test velocity:30 s 50% maximal test velocity) and sprint-interval (work:rest = 30 s all out:4 min passive rest) training for eight weeks. Furthermore, very likely moderate improvements were observed in aerobic power and repeated sprint ability following the sprint-interval training. When the training time available is limited or during certain phases of the season (e.g., between tournaments), low-volume HIIT might provide a time-efficient alternative to improve athletes' fitness qualities. For example, six sprint-interval training sessions (work:rest = 30 s all out:4 min active recovery) completed over two weeks have been shown to result in very likely small improvements in the prone Yo-Yo IR1 performance in male academy Rugby League players (Dobbin et al., 2020), and to possible to very likely small improvements in aerobic power and Yo-Yo IR1 in male semi-professional Soccer players (Macpherson & Weston, 2015). However, no studies on low-volume HIIT have been conducted in Rugby Sevens.

The assessment of performance changes following HIIT usually includes measures of aerobic fitness (Koral et al., 2018; Macpherson & Weston, 2015; Robineau et al., 2017). Nevertheless, the evaluation of maximal sprinting speed (MSS) in addition to aerobic fitness has received growing attention in the literature. Blondel et al. (Blondel et al., 2001) introduced the term anaerobic speed reserve (ASR), which refers to the difference between MSS and MAS. Different determinants underpin these two locomotor speeds, where the availability of metabolic energy primarily governs MAS and the application of musculoskeletal forces underpins MSS (Bundle & Weyand, 2012). Therefore, the ASR allows the simultaneous assessment of both metabolic and mechanical/neuromuscular limitations of an athlete's profile (Sandford, 2018).

To date, there has been no studies exploring the effects of HIIT in female Rugby Sevens players. Therefore, considering that adaptations to HIIT likely depend on the protocol employed and on athletes' characteristics (e.g., sex and training status) (Buchheit & Laursen, 2013), this pilot study investigates the effects of two low-volume HIIT on the locomotor profile (MAS, MSS, and ASR) of female Rugby Sevens players.

Methods

Approach to the problem

A pre-post crossover study design was originally planned to address the research question. However, because of the training restrictions put in place in 2020 in response to COVID-19, only one training block of the two planned was completed. Therefore, this resulted in a pre-post parallel group design being employed to investigate the effects of two low-volume HIIT programmes on the locomotor profile (MAS, MSS, and ASR) of female Rugby Sevens athletes. Participants were randomly assigned either to a long-interval or short-interval group and completed the designated HIIT modality twice per week for three consecutive weeks during their team's preparation phase.

Participants

Eight professional female Rugby Sevens players (age: 24 ± 3 years, height: 1.60 ± 0.02 m, body mass: 63.1 ± 5.8 kg) playing for the same Rugby team took part in the study. In addition to the HIIT programme, all participants completed the same speed (2 times/week), Rugby (3 times/week) and gym (3 times/week) training sessions throughout the study duration as part of their normal team training. Approval was granted from the University of Waikato Human Research Ethics Committee (HREC#2018-10).

Procedures

Pre- and post-training testing occurred one week before and one week after the first and last training session, respectively. MSS and MAS were assessed in the same session, in this order, following a standardised warm up comprising of jogging, dynamic stretches, running drills, and stride outs. A 10-minute rest was given between tests. Physical testing was performed outdoors, on the same artificial turf wearing Rugby boots, at the same time of the day. Participants were advised to rest for 48 h before each testing session. Strong verbal encouragement was given throughout the tests. The same primary investigator (F.S.S.) conducted all testing and training sessions.

Maximal sprinting speed (MSS)

The MSS was determined using the 30-40 m split time over a 40-m sprint distance on a grass track. Sprint time was measured to the nearest 0.01 second using single beam timing lights

(Brower Timing System, Utah, USA). The first gate was set at a height of 0.5 m while the remaining were set at 0.75 m. Participants started each sprint in a standing split position 0.5 m behind the first gate and were instructed to "run as fast as possible" past the last gate. Each participant completed two maximal effort sprints, separated by 3-5 min rest. The fastest 30-40 m split time was transformed into speed and used for analysis (MSS = 10 m/time expressed in $m \cdot s^{-1}$). Sprint times in female Rugby Sevens players using similar equipment have demonstrated excellent test-retest reliability for 30-m and 40-m based on intraclass correlation coefficient (ICC) values of 0.95 and 0.96, respectively (Goodale et al., 2016).

Maximal aerobic speed (MAS)

The MAS, defined as the lowest speed that elicits $\dot{V}O_2$ max (Billat & Koralsztein, 1996), was predicted using a 2-km time trial performed around a grass track (Bellenger et al., 2015). Total time to complete 2-km on a grass track was recorded using a stopwatch; thereafter, the MAS of each participant was calculated by dividing the total distance covered by the time taken to complete it. Participants were instructed to give a maximal effort. Time-trial tests over various distances have demonstrated good to excellent test-retest reliability in male runners, with ICC values of 0.88 to 0.95 and coefficient of variation (CV) values of 2.2 to 3.3% (Laursen et al., 2007).

Anaerobic speed reserve (ASR)

The ASR was calculated as the difference between MSS and MAS (ASR = MSS – MAS) as reported in Blondel et al. (Blondel et al., 2001).

Training intervention

Participants completed either a long-interval or short-interval HIIT programme twice per week, for three consecutive weeks. The long-interval protocol consisted of 40 s of work alternated with 20 s of passive rest. The short-interval protocol consisted of 15 s of work and 45 s of passive rest. The selection of the work to rest ratios employed was informed by previous match data collected on the team (i.e., frequent ball in play and recovery cycles) and allowed to compare two training protocols comprising one running bout per minute, but of a different working duration. Despite both HIIT protocols falling in the short-interval category according to the classification of Buchheit and Laursen (2013), the long-interval and short-interval nomenclature was used to differentiate between the two training interventions throughout the study. In both groups, participants were instructed to give a maximal effort throughout each repetition for the duration of the work period, with strong verbal encouragement given. All workouts were performed outdoor on a Rugby field, following a 15 min warm up comprised of jogging, dynamic stretches, running drills, and stride outs. The HIIT sessions were never performed on consecutive days and were separated by at least 48 hrs.

The sessions training details and progression employed are reported in Table 10. The two HIIT protocols included the same number of intervals in every training session. Within each group, two different HIIT modalities were employed across the study. Specifically, the long-interval group performed shuttle runs over 50 m and a Rugby-specific drill. The short-interval group completed straight line running and a Rugby-specific drill. The Rugby-specific drill was the same for both groups and is outlined in Figure 4. The drill was developed in conjunction with the team coaching staff to mimic the demands and movement patterns of the Rugby Sevens game (Furlan et al., 2016; Ross et al., 2015a), including straight line running, change of direction at different angles, down and ups, and tackling. The Rugby-drill was performed both clockwise and anti-clockwise, alternating the direction of running between sessions. Every participant started each interval from a different white cone to avoid any interference with others (Figure 4).

Table 10. High-intensity interval training programmes.

	Week 1		Week 2		Week 3	
	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6
Long-interval group (work:rest = 40:20 s)						
Sets x repetitions	2 x 8	2 x 8	2 x 9	2 x 9	2 x 9	2 x 9
Training type	Set 1: Shuttles over 50 m	Set 1: Rugby-drill	Set 1: Rugby-drill	Set 1: Shuttles over 50 m	Set 1: Shuttles over 50 m	Set 1: Rugby-drill
	Set 2: Shuttles over 50 m	Set 2: Rugby-drill	Set 2: Shuttles over 50 m	Set 2: Rugby-drill	Set 2: Rugby-drill	Set 2: Shuttles over 50 m
Short-interval group (work:rest = 15:45 s)						
Sets x repetitions	2 x 8	2 x 8	2 x 9	2 x 9	2 x 9	2 x 9
Training type	Set 1: Straight line	Set 1: Rugby-drill	Set 1: Straight-line	Set 1: Rugby-drill	Set 1: Rugby-drill	Set 1: Straight-line
	Set 2: Straight line	Set 2: Rugby-drill	Set 2: Rugby-drill	Set 2: Straight line	Set 2: Straight line	Set 2: Rugby-drill

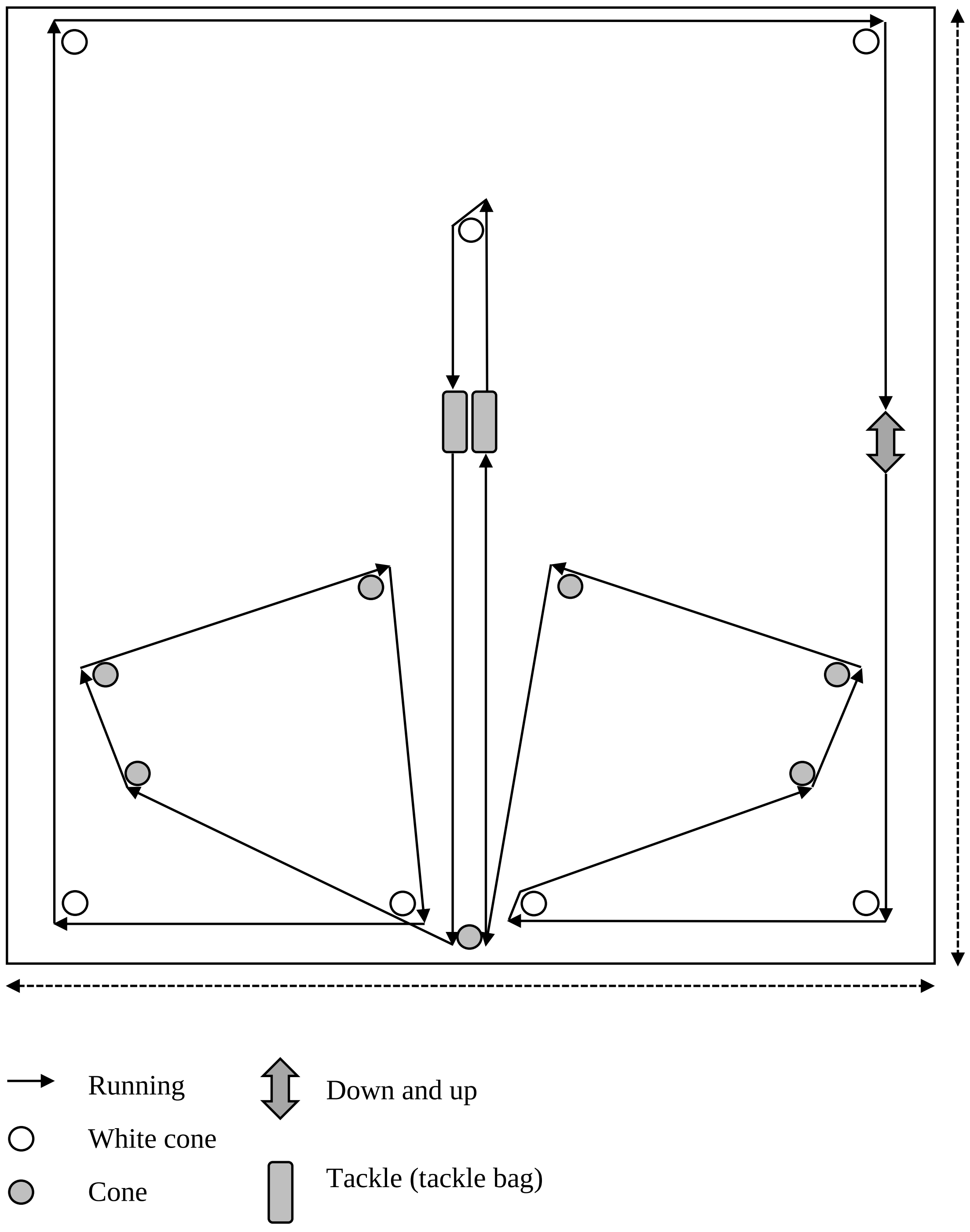

Figure 4. Rugby-specific drill

Statistical analysis

All data were log-transformed prior to analyses. However, for clarity, the values presented in the manuscript are not log-transformed. Within- and between-group changes in MAS, MSS, and ASR mean values were evaluated using standardisation, and with the clinical version of magnitude-based inferences (Hopkins, 2017b; Hopkins et al., 2009). All analyses were adjusted by using the pre-test value as a linear covariate. Given the low sample size, the between-subjects standard deviations from previous female Rugby Sevens data were used for standardisation. Effects magnitudes were interpreted using threshold values of <0.2, 0.2, 0.6, 1.2, 2.0, and 4.0 as trivial, small, moderate, large, very large, and extremely large differences, respectively (Hopkins et al., 2009). Probabilities were also calculated to establish whether the "true" changes were lower, similar or higher than the smallest worthwhile change (0.2 x between-subjects standard deviation). Quantitative chances of higher or lower changes were evaluated qualitatively as follows: <1%, almost certainly not; 1−5%, very unlikely; 5−25%, unlikely; 25−75%, possible; 75−95%, likely; 95−99%, very likely; >99%, almost certain (Hopkins et al., 2009). An effect was defined clinically beneficial when the chance of benefit was >25% (possible) and the chance of harm <0.5% (most unlikely) (Hopkins et al., 2009). If the effect was possibly beneficial (>25%) but with unacceptable risk of harm (>0.5%) the effect was clinically unclear (Hopkins, 2017b).

Results

One player from the long-interval group completed four out of the six training sessions scheduled, with the remaining players completing all sessions. Within- and between- groups pre-post changes are reported in Table 11; within-groups changes are also presented in Figure 5. In MAS, clear and possible harmful changes were observed following the long-interval programme and clear and possible beneficial changes following the short-interval programme, although the difference between groups was unclear. There were small positive changes in MSS following both programmes, with a small (but unclear) difference in favour of the short-interval programme. There were also small positive changes in the ASR following the long-interval programme. However, all these small changes were unclear.

Table 11. Within- and between-groups pre-post changes.

	Long-interval group (*n* = 4)				Short-interval group (*n* = 4)				Post – Pre group change	
	Pre	Post	Post-Pre		Pre	Post	Post-Pre		Short interval – Long interval	
	Mean ± SD	Mean ± SD	ES; ±90% CL	Inference[a]	Mean ± SD	Mean ± SD	ES; ±90% CL	Inference[a]	ES; ±90% CL	Inference[a]
MAS ($m{\cdot}s^{-1}$)	3.69 ± 0.20	3.65 ± 0.30	-0.16; ±0.27	Trivial ↓[0]* (3/62/35) Possibly harmful	3.87 ± 0.24	3.93 ± 0.26	0.18; ±0.13	Trivial ↑[0]* (36/64/0) Possibly beneficial	0.16; ±0.28	Trivial (37/60/3) Unclear
MSS ($m{\cdot}s^{-1}$)	7.76 ± 0.22	7.89 ± 0.36	0.45; ±1.33	Small ↑ (68/18/15) Unclear	7.49 ± 0.22	7.62 ± 0.31	0.43; ±1.07	Small ↑ (70/18/11) Unclear	0.21; ±1.65	Small ↑ (51/19/30) Unclear
ASR ($m{\cdot}s^{-1}$)	4.06 ± 0.34	4.24 ± 0.56	0.35; ±0.76	Small ↑ (69/23/8), Unclear	3.62 ± 0.21	3.69 ± 0.28	0.17; ±0.70	Trivial (45/42/13) Unclear	0.12; ±1.11	Trivial (44/29/27) Unclear

ASR = Anaerobic speed reserve, CL = Confidence limits, ES = Effect size, MAS = Maximal aerobic speed, MSS = Maximal sprinting speed, SD = Standard deviation.
↑ and ↓ indicate a substantial positive and negative effect, respectively.
Reference-Bayesian likelihoods of substantial change: *possibly; **likely; ***very likely; ****most likely.
Reference-Bayesian likelihoods of trivial change: [0]possibly; [00]likely; [000]very likely, [0000]most likely.

[a]Likelihood (%): positive/trivial/negative.

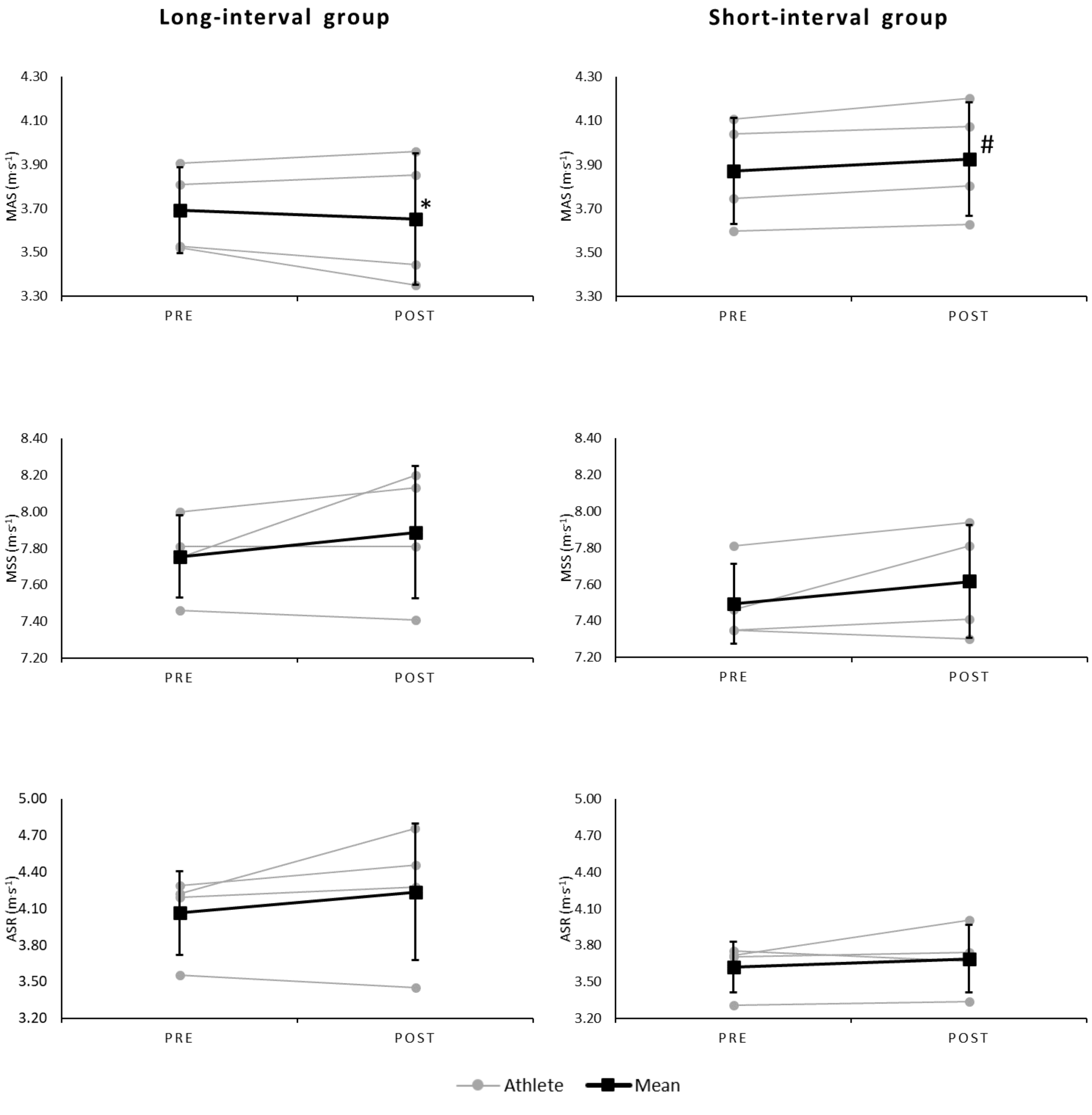

Figure 5. Pre-Post changes in maximal aerobic speed (MAS), maximal sprinting speed (MSS), and anaerobic speed reserve (ASR). Data are presented as individual data points (Athlete) and group mean ± standard deviation (Mean)

*possibly harmful; #possibly beneficial.

Discussion

In this pilot study we investigated the effects of two different low-volume HIIT protocols on the locomotor profile of female Rugby Sevens players. In MAS, there were clear and possible beneficial changes following the short-interval programme, and clear and possible harmful changes following the long-interval programme. Small but unclear positive changes were observed in MSS following both programmes and, in ASR following the long-interval programme. This pilot study provides preliminary evidence of the potential effectiveness of low-volume short-interval HIIT on MAS, whereas further evidence is required to substantiate the effectiveness of both short- and long-interval HIIT programmes on MSS and ASR in female Rugby Sevens.

Six sessions of short-interval HIIT completed over three weeks led to possible improvements in MAS in female Rugby Sevens players. Similarly, previous research has reported possible small improvements in aerobic power following six sprint-interval training sessions (work:rest = 30 s all out:4 min active recovery) completed over two weeks in male semi-professional Soccer players (Macpherson & Weston, 2015). In addition, very likely small improvements in the prone Yo-Yo IR1 performance were observed in male academy Rugby League players following the same training regime (Dobbin et al., 2020).

In contrast to the above-mentioned results seen for the short-interval HIIT (work:rest = 15:45 s), six sessions of long-interval HIIT (work:rest = 40:20 s) had a possible harmful effect on MAS. Given the training protocol involved relatively long work durations alternated with short rest periods, the training intensity attained in the long-interval group might have not been enough to maintain or improve the aerobic fitness level in some athletes (Figure 5). Since both the training and the testing sessions required maximal efforts, it is also possible that the degree of individual effort put might have affected the testing score. Of note, one of the four players in the long-interval group did not complete all the training sessions scheduled (four out of six).

Small but unclear positive changes were observed in MSS following both short-interval and long-interval training interventions. Similarly, in male professional Soccer players there were small but unclear changes in 20 and 40 m sprint performance following three weeks of the same short-interval protocol employed in this study (work:rest = 20:40 s) or a sprint-interval training programme (work:rest = 20:120 s) (Iaia et al., 2015). In both studies, participants completed technical/tactical skill training for the duration of the intervention period. Furthermore, in the current study, all players performed two speed sessions per week during the training period. Nevertheless, it appears that a greater sample size would be required to confirm the potential effect of the trainings completed on maximal sprinting performance.

In recent years, the evaluation of the ASR has become popular among researchers and practitioners, since it allows to simultaneously assess both metabolic and mechanical/neuromuscular limitations of an athlete's profile (Sandford, 2018). In support of this, previous research conducted in Soccer players has suggested the usefulness of assessing athletes' locomotor profile (i.e., MAS, MSS, and ASR) in relation to repeated sprint ability (Buchheit & Mendez-Villanueva, 2014) and supramaximal running speed (Buchheit & Mendez-Villanueva, 2013). A novel aspect of this study was the assessment of changes in the ASR following HIIT in Rugby players. At a group-level, small but unclear pre-post changes were observed in the ASR following long-interval and trivial but unclear changes following the short-interval training. However, a variety of responses could be seen at individual-level (Figure 5). The ASR is defined as the difference between an athlete's MSS and MAS; therefore, considering how the positive and negative changes in MAS and MSS subsequently affect ASR becomes important for the interpretation of these adaptations. For example, if an athlete maintains MSS and increases MAS, the athlete reduces the proportion of ASR that is used during supramaximal exercise (i.e., above MAS), which results in a lower anaerobic system contribution and diminished accumulation of fatigue-related metabolites (Buchheit & Mendez-Villanueva, 2014). This physiological shift, in turn, leads to higher exercise tolerance (Bundle et al., 2003) and likely better repeated sprint ability (Buchheit & Mendez-Villanueva, 2014). Similarly, if MAS is maintained and MSS is improved, the athlete will likely increase time to exhaustion for intensities above MAS (Clarke et al., 2016) and supramaximal intermittent running performance (Buchheit & Mendez-Villanueva, 2013). In contrast, a decrease in MAS with an unchanged MSS will unlikely transfer into improved repeated-sprint performance (Buchheit & Mendez-Villanueva, 2014).

In addition to traditional HIIT consisting of running efforts in straight line and/or shuttle runs, this study included Rugby-specific activities as part of the HIIT protocols, such as changes of directions at different angles, tackles, and down and ups. These actions, when combined with running, impose a greater physiological, metabolic, and perceptual load compared to running alone (Dobbin et al., 2020; Dobbin et al., 2018b; Johnston & Gabbett, 2011; Mullen et al., 2015). Therefore, incorporating some of these activities within traditional running-based conditioning sessions might provide a better reflection of the metabolic and physiological responses typically observed during match play (Dobbin et al., 2018b; Mullen et al., 2015), and it might also increase players' training motivation.

This study is not without limitations. Firstly, the menstrual cycle and oral contraceptive status of participants were not recorded, which could have influenced the results of testing; in particular, high levels of oestrogens might have promoted greater MAS performance (Oosthuyse & Bosch, 2010). Unlike many HIIT protocols where a specific intensity and total workload (e.g., distance) is prescribed for each athlete in every training session, both long-interval and short-interval training programmes did not have a set working intensity and relied on the participants to attain intensities sufficient to elicit adaptation. Individual intensities might have varied between athletes and training sessions. In addition, due to the small number of participants, no differences in the training response were assessed between backs and forwards. A greater sample size is required to confirm these results and obtain more evidence about the magnitude of the unclear changes observed in this study (i.e., MSS and ASR). Future studies are needed to investigate the relationship between athletes' individual locomotor profile (i.e., MAS, MSS, and ASR) and the magnitude of changes in these qualities following different HIIT programmes, as well as how these changes affect on-field performance. Furthermore, employing a crossover study design would allow to identify responders and non-responders to different HIIT protocols and better understand the most effective types of HIIT for each athlete.

Practical applications

Low-volume short-interval HIIT could be beneficial for improving MAS in female Rugby Sevens players. In contrast, six sessions of long-interval HIIT were not sufficient to stimulate any positive adaptations in MAS at a group-level, possibly because of the nature of the training programme employed (i.e., work:rest ratio, intensity). Larger sample sizes are needed to improve the evidence about the magnitude of the unclear changes observed on MSS and ASR. Considering how changes in MAS and MSS affect the ASR in each athlete becomes important to understand the implications on performance.

Chapter 5 - The effects of menstrual cycle phase on physical performance in female Rugby athletes: A case-study

Introduction

It is well known that the physiology of women is unique and largely influenced by the menstrual cycle (Mujika & Taipale, 2019). The menstrual cycle is a biological rhythm characterised by the cyclic fluctuations of endogenous sex hormones, such as oestrogen and progesterone. A typical menstrual cycle lasts 28–32 days and consists of a follicular phase (~12–14 days; low to rising levels of oestrogens and low levels of progesterone), ovulation (~1 day, preceded by an oestrogen surge) and a luteal phase (~12–14 days; high levels of oestrogens and progesterone) (Sims & Heather, 2018).

While the primary function of oestrogen and progesterone is to support reproduction, the changing concentrations of these hormones across the menstrual cycle have also been found to affect a number of physiological systems, which in turn could have implications on sport performance (Constantini et al., 2005; de Jonge, 2003). However, research findings on this topic are conflicting, with large variance between studies. These equivocal findings are likely attributable to differences in study design, participants' characteristics, number and definition of menstrual cycle phases, phase verification methods, variables measured, and relatively small sample sizes (de Jonge et al., 2019; Julian et al., 2017; McNulty et al., 2020).

A limited number of studies have investigated the effects of menstrual cycle phase on physical performance in team sport athletes, with most of the research addressing individual sport athletes or untrained people. Previous studies conducted in female Soccer athletes revealed unclear and non-significant differences in sprint, repeated sprint ability, and jumping performance between phases (Julian et al., 2017; Somboonwong et al., 2015; Tounsi et al., 2018); however, while Tounsi et al., (2018) observed no differences in the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) between early follicular, late follicular, and luteal phases, Julian et al. (Julian et al., 2017) reported possibly better performance in the Yo-Yo Intermittent Recovery Test Level 2 during the early follicular phase compared to mid luteal (effect size, ES = 0.56). The different aerobic and anaerobic contributions to the two tests (Bangsbo et al., 2008) might explain the contrasting results.

Rugby is a high-intensity, intermittent, field-based contact sport that requires players to possess a range of physical qualities, including speed, power, strength, and fitness (Ross et al., 2014). To date, only one study (Miskec et al., 1997) has evaluated the potential influence of menstrual cycle phases in Rugby athletes. Specifically, these results highlighted no significant differences between early follicular and luteal phase on anaerobic power output during repeated high-intensity, intermittent exercise on a cycle ergometer. However, no further physical tests were conducted. There is a requirement for more ecologically valid research in this area, and specifically data that are relevant at an individual level. In support of this statement, a recent study addressing elite female rugby athletes has highlighted the importance to develop understanding on the menstrual cycle and considering its impact on training and competition on female Rugby athletes (Findlay et al., 2020). Therefore, in this case-study we investigated the potential effect of menstrual cycle phase on several physical qualities in female Rugby athletes. Due to the variability observed in the concentration of sex hormones and timing of cycle phases both between- and within-subjects (Häggström, 2014; Vescovi, 2011), participants' individual responses to cycle phases were assessed, in addition to average group responses.

Methods

Participants

Eighteen non-elite female Rugby athletes (mean ± standard deviation: age, 23 ± 3 years; height, 1.67 ± 0.05 m; body mass, 80 ± 18 kg) from the same New Zealand Provincial Union were recruited to participate. Four athletes fulfilled all inclusion criteria (age, 23 ± 4 years; height, 1.69 ± 0.05 m; body mass, 67 ± 6 kg; menstrual cycle duration, 30 ± 4 days) and were included in the analysis (Figure 6). Inclusion criteria for participation were: being injury free, the absence from any form of contraception for at least six months, having a menstrual cycle duration of 24-35 days before the beginning of the study (Lebrun et al., 1995), and completing at least one testing session in each of the four menstrual cycle phases considered. Written informed consent was obtained from each participant and approval was obtained from the University of Waikato Human Research Ethics Committee (HREC#2018-10).

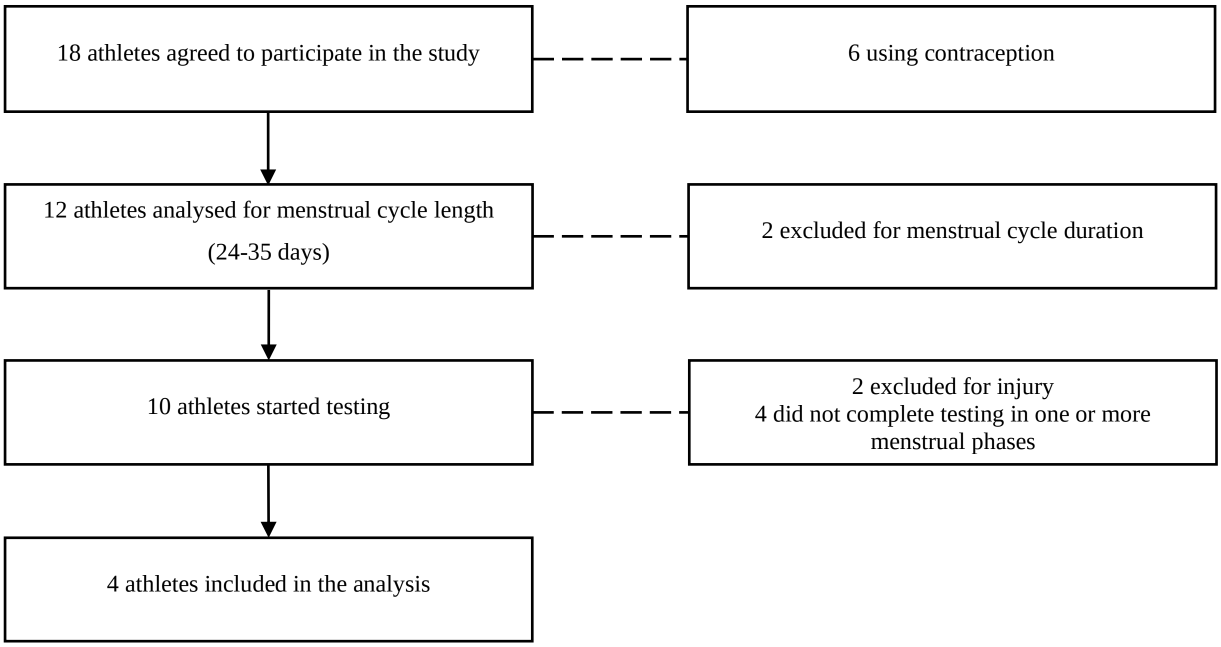

Figure 6. Participant flow chart

Study design

An observational study design with repeated measures was used. Participants completed a battery of physical tests weekly, for 5-9 consecutive weeks, during the preparation period. Concurrently, they tracked their menstrual cycle daily for the duration of the study.

Physical testing was performed weekly, irrespective of the menstrual phase for a given individual. Participants' data were de-identified to the principal investigators to maintain blinding of the menstrual cycle phase at the time of testing.

A familiarisation session was completed for all testing procedures before the start of the study. The physical assessments were conducted in the same order, on the same day of the week, at the same time of the day (Taylor et al., 2010; Teo et al., 2011) for the duration of the study. Participants were asked to standardise their dietary intake and to abstain from alcohol within the 24 hours before each test.

Physical tests

A 10-minute standardised warm up comprising of dynamic stretches, jogging, running drills, and stride outs was performed before starting the physical testing.

Acceleration. Acceleration abilities were assessed using a 10 m sprint with split times at 5 and 10 m. The test was completed indoor in running shoes using single beam timing lights (Brower Timing System, Utah, USA). The first gate was set at 0.5 m, while the remaining were set at a height of 0.75 m. Sprint times at each split were measured to the nearest 0.01 second. Participants started each sprint in a standing split position 0.5 m behind the first gate and were instructed to "run as fast as possible" past the last gate. Each participant was given one warm-up trial followed by three maximal sprints, separated by two min of rest. The repeatability for 10-m sprint times conducted under similar conditions is excellent (intraclass correlation coefficient, ICC = 0.90) (Goodale et al., 2016).

Lower-body power. Body weight countermovement jump (CMJ) and drop jump (DJ) were assessed using an optical measurement system (OptoJump Next, Microgate, Bolzano, Italy) sampling at 1000 Hz. For the CMJ, participants started from an upright standing position with their hands-on hips. Participants were instructed to "bend their knees to a self-selected depth and to jump as high as possible". For the DJ, participants stepped out and dropped off a 30 cm high box keeping their hands on their hips. Participants were instructed to "minimise time spent in contact with the ground and jump as high as possible as quickly as possible". For both jumps, one warm-up trial was given, followed by three maximal jumps separated by five seconds. The CMJ height estimated from flight time and DJ reactive strength ratio (RSR) defined as the ratio between flight time and contact time were considered for analysis. These variables (CMJ height and RSR) have been shown reliable using similar equipment based on coefficient of variation values (CV = 2.2 and 4.2%, respectively) (Byrne et al., 2017; Glatthorn et al., 2011).

Strength. Maximal strength was measured via the isometric mid-thigh pull exercise (IMTP) using a force measurement system comprising of a strain gauge load cell and software package sampling at 1000 Hz (The Strength Assessment Tool, AUT University, Auckland, NZ). The load cell was anchored to a wooden platform and connected to handles via chains. Testing protocol and position were standardised in agreement with the guidelines of Comfort et al. (e.g., knee angle 125-145°, hip angle 140-150°) (Comfort et al., 2019) and kept consistent for each athlete throughout the study. Participants were instructed to pull "as hard and as fast as possible" for three seconds. Verbal encouragement was given throughout the pull. Two sub-maximal IMTP trials at increasing intensities were given, followed by three maximal efforts interspersed by two minutes of passive rest. Peak force (PF) determined as the maximum force generated during the three seconds pull was recorded and considered for the analysis. PF assessed with a similar device has been found to be reliable (ICC = 0.96 and CV = 3.1%) (James et al., 2017).

Fitness. The 1.2 km shuttle run test, also known as Bronco test (Kelly & Wood, 2013) was used as a measure of fitness. The test was performed outdoors, on the same surface, in running shoes. The protocol consists of a continuous 20, 40, 60 m straight shuttle run, completed five times at maximal intensity (i.e., 20 m and back, 40 m and back, 60 m and back) (Kelly & Wood, 2013). Total running time was recorded and used for analysis. Excellent test-retest reliability of Bronco times has been reported (ICC = 0.99) (Brew & Kelly, 2014).

Menstrual cycle monitoring

Menstrual cycle information was tracked daily with a smartphone application (FitrWoman™). Participants started the monitoring 10 weeks prior to the start of physical testing to determine their menstrual cycle duration as required by the inclusion criteria. Participants continued to monitor their cycle throughout the 9-week duration of the study.

The length of the menstrual cycle was calculated from the first day of menses to the day preceding the next menses. By inputting typical cycle length, period duration, and the date of their last period, FitrWoman™ estimates menstrual cycle phases. The application divides the menstrual cycle duration in four phases: Phase 1 (menstruation), Phase 2 (follicular to ovulation), Phase 3 (luteal), and Phase 4 (late luteal).

Training load and well-being

The internal training load for all training sessions completed by each participant during the 5 to 9-week period was calculated using the session-RPE method (Foster et al., 2001). This method quantifies internal training load as the product of the training session rate of perceived exertion (RPE) multiplied by session duration.

The Daily Analysis of Life Demands for Athletes (DALDA) questionnaire (Rushall, 1990) was employed as a measure of well-being. The questionnaire contains 34 items to evaluate the sources and symptoms of stress. Each question can be answered either as “worse than normal”, “normal”, or “better than normal”. Participants filled the questionnaire at each testing session before the warm up.

Hydration status

To minimise the effects of hypohydration on physical performance outcome (McDermott et al., 2017), the hydration status of every participant was verified on each testing day before the warm up. Urine specific gravity (USG) was measured using urine test strips (Combur®-Test strip, Roche Diagnostics). This method has been shown to be valid and reliable ("Combur-Test® strip," 2020; Warren et al., 2018; Zubac et al., 2014). When the USG value was between 1.020 and 1.025, participants were asked to ingest a 5 ml/kg of body mass beverage (Na^{+}: 132 mg/100 ml, K^{+}: 78 mg/100 ml, CHO: 1.4 g/100 ml, mOsm/L: 230 mmol/L). With a USG of 1.030 or higher, 10 ml/kg of body mass of the same beverage was given (Sawka et al., 2007). Furthermore, if the pH value recorded was 7 or more, 0.005 was added to the USG score (Abbey et al., 2014).

Statistical analysis

At the end of the 9-week period, data were allocated into menstruation, follicular to ovulation, luteal, or late luteal phases at the date of each testing session. Except for the Bronco, the average of the best two scores achieved in the tests at every session was used for analysis. To investigate differences in physical performance between menstrual phases, physical test scores were log-transformed and analysed using the mixed linear model procedure (Proc Mixed) in the Statistical Analysis System (University Edition of SAS Studio, version 9.4, SAS Institute, Cary NC). A model was created for each physical quality of interest. Menstrual cycle phase, the mean change over the duration of the study, and the weekly training load before each testing session were included in the model as fixed effects. The differences between athletes in the middle of the study and the individual differences in the overall change were entered as random effects with an unstructured covariance matrix to allow these two effects to be correlated.

Mean changes between phases were estimated using magnitude-based inferences with 90% CI (Hopkins, 2006) and are presented as a percent. Furthermore, the effects of training load on the physical tests results were quantified using the same approach. Quantitative chances of higher or lower differences were evaluated qualitatively as follows: <0.5%, most unlikely; 0.5−5%, very unlikely; 5−25%, unlikely; 25−75%, possibly; 75−95%, likely; 95−99.5%, very likely; >99.5%, most likely. If the probabilities of the true value being substantially higher and lower were both >5%, the difference was termed as unclear.

Individual differences between the mean score for each menstrual phase with the mean predicted by the trend of the other three phases were assessed for each physical quality (Hopkins, 2017a). Specifically, the residual obtained from the mixed linear model was used as typical error in percent units. The smallest worthwhile change (SWC = 0.2 x between-subjects SD) calculated from previous data collected in our lab was used to establish the smallest important change in percent units. Quantitative chances of higher or lower differences were evaluated qualitatively as follows: <10%, very unlikely; 10−90%, possible; >90%, very likely. If the probabilities of the true value being substantially higher and lower were both >10%, the difference was termed as unclear.

With regards to wellness, DALDA responses were coded as 1 = "worse than normal", 2 = "normal", and 3 = "better than normal" and summed across the 34 items. The total score obtained in the questionnaire by each athlete was then rescaled to range from 0 to 100. Individual differences in the average scores between phases were interpreted as small, moderate, large, very large, and extremely large when reaching thresholds of 10, 30, 50, 70, and 90%, respectively.

Results

All data are presented as mean ± SD, unless otherwise indicated. The maximum variation in cycle length throughout the study was five days. Individual average physical performance results specific to menstrual cycle phase and the number of testing sessions completed in every phase by each participant are reported in Table 12.

Mean differences in physical performance between menstrual cycle phases are reported in Table 13. At a group-level, possible lower CMJ performance was observed in the menstruation phase compared to late luteal (Δ% = -4.9%). Possible lower DJ performance was observed in the luteal phase compared to late luteal (Δ% = -7.0%). Furthermore, possible lower IMTP performance was observed in the follicular to ovulation phase compared to late luteal (Δ% = -6.0%). All other phase differences were possible to very likely trivial or unclear.

Individual differences in physical performance are reported in Table 14. One participant had very likely slower 5-m time in the luteal phase compared with the trend of the other three phases. Another athlete displayed possible greater IMTP performance in the menstruation phase compared with the trend of the other three phases. With regards to the Bronco test, one athlete showed very likely trivial differences between the follicular to ovulation phase with the trend of the other three phases, and between the luteal phase with the trend of the other three phases; furthermore, another athlete displayed a possible trivial difference between the late luteal phase with the trend of the other three phases. The remaining comparisons were unclear or were scored both as a possible substantial increase or decrease and a possible trivial difference.

Training load had a possible to very likely trivial effect on Bronco, CMJ, DJ, 5-m, and 10-m speed scores. An unclear effect was registered for the IMTP. Trivial to small differences were observed in well-being (DALDA) between phases at an individual level (Figure 7).

Table 12. Individual average physical performance results specific to menstrual cycle phase across 5 to 9 weeks.

Test	Phase[a]	Participants			
		1	2	3	4
5-m time (s)	Phase 1 (*n*)	1.14 ± NA (*1*)	1.08 ± NA (*1*)	1.12 ± NA (*1*)	1.06 ± 0.00 (*2*)
	Phase 2 (*n*)	1.15 ± 0.02 (*4*)	1.08 ± 0.00 (*2*)	1.12 ± 0.03 (*4*)	1.07 ± 0.01 (*2*)
	Phase 3 (*n*)	1.14 ± 0.03 (*3*)	1.07 ± 0.01 (*2*)	1.11 ± 0.03 (*3*)	1.12 ± 0.05 (*2*)
	Phase 4 (*n*)	1.16 ± NA (*1*)	1.07 ± 0.01 (*2*)	1.12 ± NA (*1*)	1.07 ± 0.01 (*2*)
10-m time (s)	Phase 1 (*n*)	1.96 ± NA (*1*)	1.82 ± NA (*1*)	1.95 ± NA (*1*)	1.85 ± 0.01 (*2*)
	Phase 2 (*n*)	1.94 ± 0.01 (*4*)	1.82 ± 0.02 (*2*)	1.93 ± 0.04 (*4*)	1.87 ± 0.01 (*2*)
	Phase 3 (*n*)	1.94 ± 0.04 (*3*)	1.83 ± 0.02 (*2*)	1.92 ± 0.07 (*3*)	1.89 ± 0.05 (*2*)
	Phase 4 (*n*)	1.95 ± NA (*1*)	1.81 ± 0.02 (*2*)	1.93 ± NA (*1*)	1.84 ± 0.01 (*2*)
CMJ height (cm)	Phase 1 (*n*)	34.0 ± NA (*1*)	35.7 ± 5.4 (*2*)	29.7 ± NA (*1*)	35.5 ± 1.9 (*2*)
	Phase 2 (*n*)	34.9 ± 1.7 (*4*)	38.7 ± NA (*1*)	29.2 ± 2.3 (*4*)	35.2 ± 2.6 (*2*)
	Phase 3 (*n*)	33.9 ± 1.2 (*3*)	38.4 ± 0.3 (*2*)	30.0 ± 0.6 (*3*)	33.3 ± 4.5 (*2*)
	Phase 4 (*n*)	36.7 ± NA (*1*)	37.8 ± 0.0 (*2*)	27.9 ± NA (*1*)	36.4 ± 2.9 (*2*)
DJ RSR (ratio)	Phase 1 (*n*)	1.37 ± NA (*1*)	1.65 ± NA (*1*)	1.37 ± NA (*1*)	1.41 ± 0.07 (*2*)
	Phase 2 (*n*)	1.32 ± 0.17 (*3*)	1.55 ± NA (*1*)	1.24 ± 0.14 (*3*)	1.39 ± 0.16 (*2*)
	Phase 3 (*n*)	1.28 ± 0.11 (*3*)	1.70 ± 0.09 (*2*)	1.30 ± 0.08 (*3*)	1.27 ± NA (*1*)
	Phase 4 (*n*)	1.39 ± NA (*1*)	1.69 ± 0.06 (*2*)	1.23 ± NA (*1*)	1.50 ± 0.09 (*2*)
IMTP PF (N)	Phase 1 (*n*)	1702 ± NA (*1*)	1833 ± NA (*1*)	1850 ± NA (*1*)	1750 ± 198 (*2*)
	Phase 2 (*n*)	1588 ± 218 (*3*)	1506 ± 415 (*2*)	1628 ± 106 (*3*)	2091 ± 521 (*2*)
	Phase 3 (*n*)	1630 ± 113 (*3*)	1538 ± 136 (*2*)	1599 ± 123 (*3*)	1949 ± NA (*1*)
	Phase 4 (*n*)	1615 ± NA (*1*)	1748 ± 74 (*2*)	1745 ± NA (*1*)	1772 ± 592 (*2*)
Bronco time (s)	Phase 1 (*n*)	360 ± NA (*1*)	310 ± NA (*1*)	335 ± NA (*1*)	338 ± 21 (*2*)
	Phase 2 (*n*)	353 ± 4 (*4*)	303 ± NA (*1*)	346 ± 13 (*4*)	333 ± 4 (*2*)
	Phase 3 (*n*)	355 ± 5 (*3*)	319 ± NA (*1*)	342 ± 19 (*3*)	338 ± 1 (*2*)
	Phase 4 (*n*)	352 ± NA (*1*)	318 ± 1 (*2*)	339 ± NA (*1*)	331 ± 6 (*2*)

Data are presented as mean ± SD.
CMJ = Countermovement jump, DJ = Drop jump, IMTP = Isometric mid-thigh pull, *n* = Number of testing sessions completed, NA = Not applicable, PF = Peak force, RSR = Reactive strength ratio.

[a]Phase 1, menstruation; Phase 2, follicular to ovulation; Phase 3, luteal; Phase 4, late luteal.

Table 13. Mean differences between menstrual cycle phases.

Test	Phases[a]	Difference (%)	90% confidence limits		Inference[b]
			Lower	Upper	
5-m time (s)	Ph1 – Ph2	-0.6	-2.5	1.4	6/68/26, Unclear
	Ph1 – Ph3	-0.5	-2.5	1.4	6/68/26, Unclear
	Ph1 – Ph4	0.0	-2.2	2.0	14/70/16, Unclear
	Ph2 – Ph3	0.0	-1.4	1.5	8/85/7, Unclear
	Ph2 – Ph4	0.5	-1.3	2.3	23/72/5, Unclear
	Ph3 – Ph4	0.5	-1.4	2.3	23/71/6, Unclear
10-m time (s)	Ph1 – Ph2	-0.1	-1.6	1.3	5/86/9, Unclear
	Ph1 – Ph3	0.2	-1.4	1.7	11/83/6, Unclear
	Ph1 – Ph4	0.5	-1.1	2.1	19/77/4, Likely ↔
	Ph2 – Ph3	0.3	-0.8	1.4	7/92/1, Likely ↔
	Ph2 – Ph4	0.6	-0.8	2.0	21/78/1, Likely ↔
	Ph3 – Ph4	0.3	-1.2	1.8	14/82/4, Likely ↔
CMJ height (cm)	Ph1 – Ph2	-2.2	-6.3	2.1	1/78/21, Likely ↔
	Ph1 – Ph3	-2.6	-6.7	1.6	0/74/26, Possibly ↔ ↓
	Ph1 – Ph4	-4.9	-9.2	-0.4	0/39/61, Possibly ↓↔
	Ph2 – Ph3	-0.4	-3.8	3.1	2/94/4, Likely ↔
	Ph2 – Ph4	-2.7	-6.8	1.5	0/72/28, Possibly ↔ ↓
	Ph3 – Ph4	-2.3	-6.5	2.0	1/76/23, Likely ↔
DJ RSR (ratio)	Ph1 – Ph2	1.5	-6.2	9.6	15/79/6, Unclear
	Ph1 – Ph3	3.0	-4.4	11.0	24/74/2, Possibly ↔
	Ph1 – Ph4	-4.2	-11.6	3.7	2/63/35, Possibly ↔ ↓
	Ph2 – Ph3	1.5	-4.7	8.1	11/86/3, Likely ↔
	Ph2 – Ph4	-5.6	-12.1	1.4	1/53/46, Possibly ↔ ↓
	Ph3 – Ph4	-7.0	-13.2	-0.3	0/39/61, Possibly ↓↔
IMTP PF (N)	Ph1 – Ph2	5.1	-4.3	15.5	59/35/6, Unclear
	Ph1 – Ph3	3.0	-6.2	13.0	44/45/11, Unclear
	Ph1 – Ph4	-1.1	-10.5	9.2	20/47/33, Unclear
	Ph2 – Ph3	-2.1	-9.2	5.4	10/55/35, Unclear
	Ph2 – Ph4	-6.0	-13.6	2.4	3/29/68, Possibly ↓↔
	Ph3 – Ph4	-4.0	-11.9	4.7	7/41/52, Unclear
Bronco time (s)	Ph1 – Ph2	0.4	-7.8	9.3	14/74/12, Unclear
	Ph1 – Ph3	0.2	-2.3	2.7	3/95/2, Very likely ↔
	Ph1 – Ph4	-0.4	-3.8	3.1	5/87/8, Likely ↔
	Ph2 – Ph3	-0.2	-5.2	5.0	8/84/8, Unclear
	Ph2 – Ph4	-0.8	-3.1	1.5	1/94/5, Likely ↔
	Ph3 – Ph4	-0.6	-3.1	1.9	1/94/5, Likely ↔

CMJ = Countermovement jump, DJ = Drop jump, IMTP = Isometric mid-thigh pull, PF = Peak force, RSR = Reactive strength ratio.
↑ Substantial increase; ↔ Trivial; ↓ Substantial decrease.

[a]Phase 1 (Ph 1), menstruation; Phase 2 (Ph 2), follicular to ovulation; Phase 3 (Ph 3), luteal; Phase 4 (Ph 4), late luteal.
[b]Likelihood (%): increase/trivial/decrease.

Table 14. Individual menstrual cycle phase differences.

Test	Phases[a]	Participants 1	2	3	4
		Inference[b]	Inference[b]	Inference[b]	Inference[b]
5-m time (s)	Ph 1 - Trend	20/38/42, Unclear	38/45/17, Unclear	41/42/17, Unclear	7/39/54, Possible ↓↔
	Ph 2 - Trend	12/49/39, Unclear	33/54/14, Unclear	31/51/17, Unclear	39/41/20, Unclear
	Ph 3 - Trend	13/61/26, Unclear	12/60/29, Unclear	13/56/31, Unclear	96/3/0, Very likely ↑
	Ph 4 - Trend	41/43/16, Unclear	12/61/27, Unclear	22/35/43, Unclear	7/35/58, Possible ↓↔
10-m time (s)	Ph 1 - Trend	39/47/14, Unclear	32/54/15, Unclear	52/40/8, Possible ↑↔	13/61/26, Unclear
	Ph 2 - Trend	17/59/24, Unclear	21/65/14, Unclear	20/51/29, Unclear	51/44/5, Possible ↑↔
	Ph 3 - Trend	2/71/27, Possible ↔↓	19/70/11, Unclear	17/62/21, Unclear	69/30/1, Possible ↑↔
	Ph 4 - Trend	26/55/19, Unclear	6/67/27, Possible ↔↓	26/38/37, Unclear	1/32/67, Possible ↓↔
CMJ height (cm)	Ph 1 - Trend	5/37/59, Possible ↓↔	0/28/72, Possible ↓↔	21/60/19, Unclear	15/67/18, Unclear
	Ph 2 - Trend	23/63/14, Unclear	6/36/58, Possible ↓↔	2/83/15, Possible ↔↓	1/36/62, Possible ↓↔
	Ph 3 - Trend	2/52/45, Possible ↔↓	72/28/1, Possible ↑↔	29/62/9, Possible ↔↑	5/56/39, Possible ↔↓
	Ph 4 - Trend	73/26/1, Possible ↑↔	21/66/13, Unclear	19/49/32, Unclear	76/24/0, Possible ↑↔
DJ RSR (ratio)	Ph 1 - Trend	11/41/48, Unclear	32/55/13, Unclear	50/43/7, Possible ↑↔	23/55/22, Unclear
	Ph 2 - Trend	31/61/8, Possible ↔↑	7/44/49, Possible ↓↔	3/70/27, Possible ↔↓	12/52/36, Unclear
	Ph 3 - Trend	3/44/53, Possible ↓↔	20/62/18, Unclear	34/42/23, Unclear	2/23/75, Possible ↓↔
	Ph 4 - Trend	72/26/2, Possible ↑↔	17/74/9, Possible ↔↑	26/44/29, Unclear	85/15/0, Possible ↑↔
IMTP PF (N)	Ph 1 - Trend	44/24/32, Unclear	44/26/30, Unclear	89/8/3, Possible ↑	4/18/79, Possible ↓↔
	Ph 2 - Trend	14/37/50, Unclear	10/17/73, Unclear	13/35/52, Unclear	56/26/19, Unclear
	Ph 3 - Trend	27/37/36, Unclear	32/31/37, Unclear	10/21/68, Unclear	51/26/22, Unclear
	Ph 4 - Trend	42/28/31, Unclear	81/16/3, Possible ↑↔	47/24/29, Unclear	44/27/29, Unclear
Bronco time (s)	Ph 1 - Trend	27/66/7, Possible ↔↑	15/71/14, Unclear	4/53/43, Possible ↔↓	17/79/3, Possible ↔↑
	Ph 2 - Trend	5/94/2, Very likely ↔	5/53/42, Possible ↔↓	27/66/7, Possible ↔↑	3/60/37, Possible ↔↓
	Ph 3 - Trend	5/90/4, Very likely ↔	21/70/9, Possible ↔↑	13/75/12, Unclear	42/56/3, Possible ↔↑
	Ph 4 - Trend	10/72/18, Unclear	5/85/10, Possible ↔	18/53/30, Unclear	5/72/23, Possible ↔↓

CMJ = Countermovement jump, DJ = Drop jump, IMTP = Isometric mid-thigh pull, PF = Peak force, RSR = Reactive strength ratio, Trend = Value predicted by the trend of the other three phases.
↑ Substantial increase; ↔ Trivial; ↓ Substantial decrease.

[a]Phase 1 (Ph 1), menstruation; Phase 2 (Ph 2), follicular to ovulation; Phase 3 (Ph 3), luteal; Phase 4 (Ph 4), late luteal.
[b]Likelihood (%): increase/trivial/decrease.

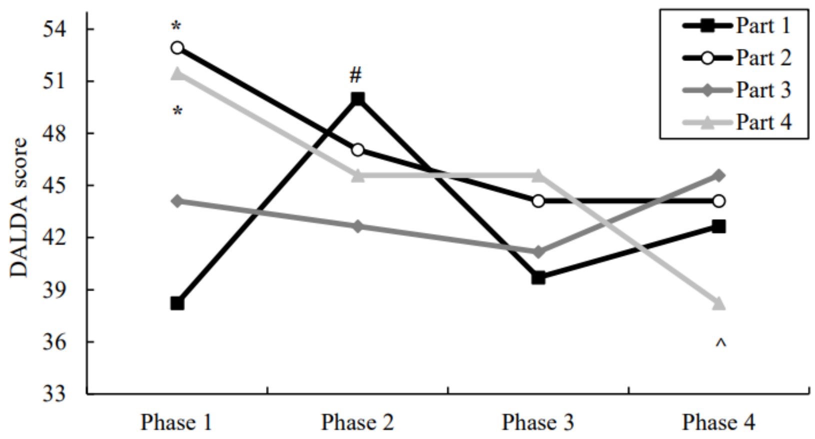

Figure 7. DALDA score specific to each participant (Part).

Data are presented as rescaled mean scores for each menstrual cycle phase. Phase 1, menstruation; Phase 2, follicular to ovulation; Phase 3, luteal; Phase 4, late luteal.

* = Small difference with Phase 2, Phase 3, and Phase 4. # = Small difference with Phase 1, Phase 3, and Phase 4. ^ = Small difference with Phase 2 and Phase 3.

Discussion

This is the first study investigating the effects of menstrual cycle phase on several physical qualities in Rugby athletes over multiple testing sessions. The inclusion and analysis of participants' individual responses to cycle phase, in addition to the group average responses, also represent a novelty.

In female Rugby athletes, possibly greater CMJ performance was observed in the late luteal phase compared with the menstruation phase, with possible to likely trivial changes observed between the other phases. Previous research conducted on female Soccer athletes reported unclear differences in CMJ height between early follicular and mid luteal phase (Julian et al., 2017). The different study design, menstrual cycle phases considered, and phase verification methods might explain the conflicting results. In the current study, possibly greater DJ performance was observed in the late luteal phase compared with the luteal phase, with the remaining phase comparisons showing possible to likely trivial or unclear differences. No other studies have investigated the effects of menstrual cycle performance on DJ in team sport athletes. However, previous research reported no significant differences in the five-jump test (Tounsi et al., 2018) between the early follicular, late follicular, and luteal phase in female Soccer athletes.

Possible greater peak force was observed in the IMTP in the late luteal phase compared with the follicular to ovulation phase in Rugby athletes. Unclear differences were observed in other phase comparisons. To the authors' knowledge, no other study has evaluated the influence of menstrual cycle on maximal isometric strength in team sport athletes using multi-joint exercises (i.e., IMTP). A study (Dos Santos Andrade et al., 2017) performed on female Soccer athletes found the hamstring/quadriceps peak torque strength balance ratio for the non-dominant limb was significantly lower ($p = 0.01$) during follicular phase compared to the luteal phase, which might have implications in terms of lower-limb and anterior cruciate ligament injury risk. In contrast, previous research (Hertel et al., 2006) assessing isokinetic concentric strength in female college students (i.e., Soccer and Cheerleading) found no substantial fluctuations in hamstring and quadriceps muscle strength across the menstrual cycle at group-level.

Unclear differences were observed across the menstrual cycle in 5-m sprint time in Rugby athletes. Furthermore, unclear differences and likely trivial differences were observed between phases in 10-m sprint time. While the trivial differences highlight the absence of a substantial change in performance between phases, the unclear differences are likely attributed to the small sample size employed in this study (Buchheit, 2018). When considering the existing research on team sports, previous studies addressing female Soccer athletes showed unclear and non-significant differences between early follicular and mid luteal phases in 5, 10, 30 m sprint times (Julian et al., 2017), and in 40-yard (~37 m) sprint time (Somboonwong et al., 2015). Furthermore, in female Soccer athletes, no significant differences were observed between early follicular, late follicular, and luteal phase in a repeated shuttle-sprint ability test (Tounsi et al., 2018).

Likely to very likely trivial or unclear menstrual phase differences characterised the Bronco test. No significant differences in fitness performance were reported between phases in female Rugby (Miskec et al., 1997) and Soccer athletes (Julian et al., 2017; Tounsi et al., 2018) in previous research. However, in the study of Julian et al. (Julian et al., 2017), female Soccer athletes covered possibly greater distance in the Yo-Yo Intermittent Recovery Test Level 2 during the early follicular phase compared to mid luteal (ES = 0.56). These findings contrast the results of this study, and may be explained by the different menstrual phases considered and the different tests employed (Sella et al., 2021b).

To date, most of the research in this area has focused on the average effects of menstrual cycle on physical performance at group-level, without considering and analysing the individual responses. However, it is known that a large inter- and intra-individual variability exist in the concentration of sex hormones and timing of cycle event (Häggström, 2014; Vescovi, 2011) that could potentially affect women differently. Therefore, tracking individual performance changes across the different phases of the cycle proves to be critical for athletes and coaches. For example, in this study, no clear differences were observed in 5-m sprint time across the menstrual cycle at group-level. However, one athlete showed very likely slower 5-m time in the luteal phase compared with the trend of the other three phases. These observations suggest impairment in her short acceleration abilities in the luteal phase, which in turn could affect game performance (Clarke et al., 2017b). Another athlete displayed possibly greater peak force in the IMTP exercise in the menstruation phase compared with the trend of the other phases, despite no clear differences were observed at group-level between the menstruation phase with the other phases; therefore, further highlighting the need to account for individual performance differences across the menstrual cycle. In collision-based sports such as rugby, high levels of muscular strength are thought to be important to success (Ross et al., 2014); in particular, peak force assessed in the IMTP appears to be associated with performance in numerous athletic tasks in a variety of athletes (Comfort et al., 2019).

It is worth noting that several phase comparisons at group-level and at individual-level, resulted both as a possible substantial increase or decrease and a possible trivial difference. These findings are explained by the magnitude of the SWCs and typical errors (TEs) of the physical tests conducted (TE ~ SWC or TE > SWC), and indicate that the ability to make firm conclusions is limited unless the probability of a substantial change is high. Throughout the study, the weekly training load completed before each testing session did not substantially affect test scores. Trivial to small differences were observed between phases in well-being on the day of testing.

It is important to highlight some limitations of the present study. Firstly, because of the long duration of the investigation, we did not measure oestrogen and progesterone concentrations to verify menstrual cycle phase and no ovulation testing was conducted. Instead, we opted for a designated smartphone application. Compared to direct hormones measurements, this method is a practical, time-efficient and cost-effective alternative to monitor the menstrual cycle (i.e., duration and phase prediction) in a team environment. However, it does not allow distinguishing between ovulatory and anovulatory or luteal phase-deficient cycles, nor does it allow for monitoring the daily variation of hormones between individuals (de Jonge et al., 2019). In addition, knowledge of hormones concentration specific to menstrual cycle phase could have also assisted in explaining performance differences at individual-level between- and within-menstrual cycle phases. Therefore, additional research is required to investigate the validity of this alternative method to monitor menstrual cycle (Julian & Sargent, 2020). While not addressed in the current study, recovery post-exercise may also differ between phases and impact on overall training outcomes.

Out of the participants that were screened for eligibility (n = 18), only four completed the study (22%, Figure 6). Large degrees of drop-out rates (75 and 82%) were also observed in previous research conducted in Soccer athletes (Julian et al., 2017; Julian et al., 2020), highlighting one of the challenges in conducting this type of research with athletic population in applied settings.

To improve the quality of menstrual cycle research, further studies are required to address the above limitations. In addition, similar to the study of Julian et al. (Julian et al., 2020) in Soccer, future research is needed to assess the influence of menstrual cycle directly on Rugby and other sports' match activities and determinants of success. Lastly, given the high prevalence of contraception in female athletes (Rechichi et al., 2009), the effects of different hormonal profiles should be also considered.

Conclusions

In female Rugby athletes, possibly greater performances were observed in the CMJ, DJ, and IMTP in the late luteal phase compared with the menstruation, luteal, and follicular to ovulation phases. However, a large variety of responses were observed at an individual-level.

Including menstrual cycle monitoring and understanding the potential effects of cycle phase on physical performance in Rugby and other team sports could be of interest for coaches and practitioners. In particular, assessing and accounting for athletes' individual changes during menstrual cycle phases will likely be beneficial for interpreting monitoring results and training prescription.

Chapter 6 - General discussion

General summary

The purpose of this Thesis was to increase the understanding of the women's Rugby Sevens game, with a particular focus on how to maximise performance. Firstly, a systematic review summarised the existing research pertaining to the anthropometric characteristics, physical qualities, and match demands (match running and physiological responses) of female Rugby Sevens athletes. An observational study was then conducted to investigate the associations between physical-test measures and match performance. One intervention study explored the effects of two low-volume high-intensity interval training (HIIT) programmes on female Rugby Sevens athletes' locomotor profile. Finally, one observational study focused on the potential effects of menstrual-cycle phase on various physical-test measures.

Literature review (Chapter 2)

To optimally prepare athletes for competition, the match demands and physical requirements of female Rugby Sevens athletes must be understood. Therefore, a systematic literature review was completed to critically appraise and summarise the research addressing the match demands (match running and physiological responses), anthropometric characteristics, and physical qualities of female Rugby Sevens athletes and to highlight differences between competition levels and playing positions.

Greater running demands and intensities, number of sprints and accelerations (ES = 0.36 to 5.52), but lower physiological responses characterised international matches compared with nationals (ES = -0.97 to -0.82). At international level, backs demonstrated greater running demands and intensities (ES = 0.86), number of sprints, and physiological responses (ES = 1.83) than forwards. Elite athletes were heavier, leaner, and taller (ES = 0.26 to 1.91), and displayed superior physical qualities (e.g., maximal speed, power, upper-body strength, and aerobic capacity) compared with nonelite athletes (ES = 0.69 to 6.19). At elite level, forwards were heavier (ES = 2.68) and displayed greater upper-body strength (ES = 0.99 to 1.34), whereas backs showed greater acceleration and maximal speed abilities (ES = 0.85 to 0.92). The specific match demands and physical requirements of female Rugby Sevens athletes competing at different playing levels and playing positions must be considered for developing effective training programmes to maximize athletes' preparation.

Match performance and physical qualities (Chapter 3)

A combination of technical, tactical, and physical factors determines success in women's Rugby Sevens (Ross et al., 2014); therefore, evaluating the relationships between physical-test measures with various match-running and match-actions measures could be useful for training prescription. In Chapter 3 we investigated these relationships.

There was good evidence of positive effects of many physical-test measures on match high-intensity running, with large effects for jump height and acceleration. There was some evidence of small-moderate positive effects of speed and Bronco, and of small-moderate negative effects of maximal strength and jump height, on match total running and high intensity changes in speed. The evidence was generally inadequate for associations between physical-test measures and match actions, but there was good evidence of small-large positive effects of back squat and jump height on tries scored. These results provide practitioners with an enhanced understanding of the relationships between physical physical-test measures and match performance. In particular, enhancing players' jump height and back-squat performance might therefore increase the likelihood of match success in women's Rugby Sevens.

Physical performance enhancement (Chapter 4 and Chapter 5)

Possessing well-developed fitness qualities has been shown to be beneficial for on-field running performance in female Rugby Sevens athletes (Clarke et al., 2017b) and to minimise fatigue during match play (Stone & Kilding, 2009; Tomlin & Wenger, 2001). In addition, better aerobic capacities were found to differentiate between Rugby Sevens athletes who played high and low minutes during a full international season (Goodale et al., 2016).

Among the different training modalities, HIIT is widely employed in Rugby to develop fitness. Therefore, in Chapter 4 we investigated the effects of two low-volume HIIT programmes in women's Rugby Sevens players. In addition to players' maximal aerobic speed (MAS), the evaluation of players' maximal sprinting speed (MSS), and the anaerobic speed reserve (ASR) – defined as the difference between MSS and MAS – allowed the simultaneous assessment of both metabolic and mechanical/neuromuscular limitations of an athlete's running profile (Sandford, 2018).

Six sessions of short-interval HIIT lead to possible improvements in MAS (ES = 0.18). In contrast, six sessions of long-interval HIIT had a possible negative effect on MAS (ES = -0.16). There were small positive changes in MSS following both programmes, and small positive changes in the ASR following the long-interval programme; however, all these changes were unclear. Considering how changes in MAS and MSS affect the ASR in each athlete becomes important to understand the implications on performance.

When working with female athletes, it is important to consider that female physiology is largely driven by the menstrual cycle, and that the changing concentrations of hormones at different stages of the menstrual cycle can influence exercise performance (Constantini et al., 2005; de Jonge, 2003). Given the limited research on this topic, the potential effect of menstrual cycle phase on several physical qualities in Rugby athletes was examined in Chapter 5. At a group-level, possible greater performances were observed in the countermovement jump during the late luteal phase compared with menstruation, in the drop jump during late luteal compared with luteal, and in the isometric mid-thigh pull during late luteal compared with follicular to ovulation (Δ% = 4.9-7.0%). A variety of responses were observed between individuals for all the tests conducted. Understanding and accounting for individual responses during the menstrual cycle will likely be beneficial to training prescription and interpreting performance monitoring results.

Strengths

The key strengths and limitations of this Thesis are reported in Table 15 for each Chapter and for the overall Thesis. One of the overall strengths of this Thesis was the breadth of study designs used, which included a comprehensive systematic review with methodological quality assessment (Chapter 2), a descriptive correlation study (Chapter 3), a pre-post parallel group experimental study (Chapter 4), and an observational study with repeated measures (Chapter 5). The studies conducted have contributed to advancing knowledge in the field of female Rugby Sevens, as supported by a number of these studies being published in peer-reviewed journals (Sella et al., 2021a; Sella et al., 2022; Sella et al., 2019). A range of progressive statistical approaches were implemented throughout this Thesis (Hopkins, 2022; Hopkins et al., 2009) that go beyond null-hypothesis testing and arguably better account for sampling uncertainty (Hopkins, 2022). Another strength of the Chapters 3 to 5 was working with female

Rugby athletes across levels of performance, from nonelite to elite athletes, in their training environments. Researchers working closely with teams and athletes is needed for knowledge translation and fostering evidence-based practice (Sandbakk, 2018). Doing so also increases the ecologically validity of the study findings and more closely represents real-world player data.

Limitations

One of the main limitations of the observational and experimental studies included in this Thesis (Chapters 3 to 5) was the relatively small sample size, as highlighted in Table 15. With only seven players on the field and five players on the bench during Rugby Sevens tournaments, Rugby Sevens teams are relatively small in numbers. The studies presented in Chapters 3 to 5 were not conducted in a chronological order because of challenges in conducting research in team sports, such as training and competition schedule, and players availability. Therefore, results from one study did not necessarily inform the design or implementation of the other studies.

Because of the limited available literature on nonelite female Rugby Sevens athletes and the lack of research reporting findings specific to backs and forwards, it was not possible to make comparisons between the match demands and physical qualities of nonelite backs and forwards in Chapter 2. Various physical tests and speed thresholds were used to assess players' physical qualities and match running demands, which limited the possible comparisons between playing levels and playing positions.

In Chapter 3, the relationships between physical-test measures and match-performance measures were examined. Since the physical tests were undertaken within a 14-day period before competition, it is possible that the relationship might differ between teams implementing different training and tapering regimes.

Unlike many high-intensity interval training protocols where a specific intensity and distance is prescribed for each athlete in every training session, both long-interval and short-interval training programs employed in Chapter 5 did not have a set working intensity and relied on the participants to attain intensities sufficient to promote adaptation. Individual intensities might have varied between athletes and training sessions. In addition, because of the training restrictions put in place in 2020 in response to COVID-19, only the first training block of the two planed training blocks was completed; what was originally a cross-over study became a pre-post parallel study.

In Chapter 5, because of the long duration of the investigation, oestrogen and progesterone concentrations were not measured to verify menstrual cycle phase and ovulation testing was not conducted. Instead, a designated smartphone application was used. Although this method is a practical and time-efficient alternative, it did not allow to differentiate between ovulatory and anovulatory or luteal phase-deficient cycles and to monitor the daily variation of hormones between individuals (de Jonge et al., 2019).

Table 15. Strengths and limitations of each Chapter and of the Thesis.

Thesis	Strengths	Limitations
Chapter 2 - Match demands, anthropometric characteristics, and physical qualities of female Rugby Sevens athletes: A systematic review	• Comprehensive systematic review of the match demands, anthropometric characteristics, and physical qualities of female Rugby Sevens players. • Highlight the differences between elite and nonelite players, and between backs and forwards at elite level. • Adherence to the structure and reporting guidelines of PRISMA. • Methodological quality assessment of the included articles using a modified version of the Downs and Black quality assessment checklist.	• Unable to make comparisons between match demands and physical qualities of nonelite backs and forwards due to the limited available literature and the lack of research reporting findings specific to backs and forwards. • Various physical tests and speed thresholds were used across the studies, which limited the possible comparisons between playing levels and playing positions.
Chapter 3 - The associations between physical-test performance and match performance in women's Rugby Sevens players	• Physical-test data collected on five different New Zealand Provincial Union teams and match data collected during the New Zealand National Rugby Sevens tournament. • First study to reveal potentially useful relationships between physical-test measures and match performance (both match-running and match-action measures) in women's Rugby Sevens players. • The analyses conducted allowed to highlight potentially implementable effects to enhance the likelihood of match success.	• The physical tests were conducted within a 14-day period before competition; therefore, it is possible that the relationship might differ between teams implementing different training and tapering regimes.

Chapter 4 - Low-volume high-intensity interval training programmes in female Rugby Sevens players: A pilot study	• First study exploring the effects of HIIT in female Rugby Sevens players. • Conducted in professional players, in applied setting using a mix of both running and Rugby-specific training methods • A novel aspect of this study was the assessment of changes in the ASR following HIIT in Rugby players.	• Because of the training restrictions put in place in response to COVID-19, only the first training block of the two planned training blocks was completed; what was originally a cross-over study became a pre-post parallel study. • Both long-interval and short-interval training programs did not have a set working intensity and relied on the participants to attain intensities sufficient to promote adaptation. Individual intensities might have varied between athletes and training sessions.
Chapter 5 - The effects of menstrual cycle phase on physical performance in female Rugby athletes: A case-study	• First study investigating the effects of menstrual cycle phase on several physical qualities in Rugby athletes. • The inclusion and analysis of participants' individual responses to cycle phase, in addition to the group average responses, represent a novelty.	• Oestrogens and progesterone concentrations were not measured to verify menstrual cycle phase and ovulation testing was not conducted. Therefore, inability to differentiate between ovulatory and anovulatory or luteal phase-deficient cycles and to monitor the daily variation of hormones between individuals.
Overall Thesis	• One of the few Thesis conducted on women's Rugby players. • A range of study designs and of progressive statistical approaches were implemented throughout this Thesis. • Studies performed in team settings (ecologically valid environment).	• Small sample size in the observational and experimental studies included in this Thesis. • The studies presented in Chapters 3-5 were not conducted in a chronological order because of challenges in conducting research in team sports, such as training and competition schedule, and players availability. Therefore, results from one study did not necessarily inform the design or implementation of the other studies.

ASR = Anaerobic speed reserve, HIIT = High-intensity interval training, PRISMA = Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

Practical applications

This Thesis intended to assist strength and conditioning coaches working in women's Rugby Sevens to understand how to maximise their athletes' performance. Based on the findings of this Thesis, the following practical applications may assist these professionals:

- Female Rugby Sevens athletes aiming to compete at the highest level should focus on developing maximal speed, lower-body power, upper-body strength, aerobic capacity, and lean muscle mass with relatively low amounts of body fat.

- At the elite level, given the specific positional roles, well-developed acceleration and maximal speed abilities would be advantageous for backs, whereas forwards would benefit by possessing well-developed upper-body strength and greater body mass.

- Enhancing players' jump height and back-squat performance might increase the likelihood of match success in women's Rugby Sevens.

- Low-volume short-interval HIIT could be beneficial for improving maximal aerobic speed in female Rugby Sevens players.

- In female Rugby athletes, at a group level, possibly greater performances were observed in the countermovement jump, drop jump, and isometric mid-thigh pull in the late luteal phase compared with the menstruation, luteal, and follicular to ovulation phases. A variety of responses were observed between individuals for all the tests conducted.

- Including menstrual cycle monitoring and understanding the potential effects of cycle phase on physical performance in Rugby could be of interest for coaches and practitioners. In particular, assessing and accounting for athletes' individual changes during menstrual cycle phases will likely be beneficial for interpreting monitoring results and training prescription.

Future research

Considering the findings, strengths, and limitations of this Thesis, the following directions for future women's Rugby Sevens research are suggested:

- Future research studies should aim to have a larger pool of players, for example by including multiple Rugby Sevens teams and working collaboratively across research centres. A larger sample size would allow to get more evidence about the magnitude of the unclear effects observed in this Thesis. Furthermore, a larger sample size would allow to make recommendations specific to backs and forwards.

- Future research could seek to include multiple linear regression and experimental studies investigating the effect of changes in physical-test measures on match performance to support the promising utility of back squat and countermovement jump for enhancing performance in women's Rugby Sevens.

- Future studies are needed to investigate the relationship between athletes' individual locomotor profile (i.e., MAS, MSS, ASR) and the magnitude of changes in these qualities following different HIIT programmes. Identifying responders and non-responders to different HIIT protocols would allow to better understand the most effective types of HIIT for each athlete.

- Further research should assess the influence of menstrual cycle directly on Rugby match-running and match-activities measures. In addition, given the high prevalence of contraception in female athletes (Rechichi et al., 2009), the effects of different hormonal profiles on physical performance should be also considered.

Conclusion

This Thesis summarises and contributes to the women's Rugby Sevens scientific literature pertaining to physical and match performance. Based on the pre-existing research, superior physical qualities characterise elite women's Rugby Sevens players compared to nonelite. In addition, at the elite level, specific physical qualities differentiate backs from forwards. This Thesis identified associations between several physical-test and match-running measures in women's Rugby Sevens; and found indications that enhancing players' jump height and back squat could increase the likelihood of match success. The experimental pilot study provided preliminary evidence that low-volume short-interval HIIT could be beneficial for improving MAS in female Rugby Sevens players. In contrast, low-volume long-interval HIIT could possibly negatively affect MAS. Finally, at a group-level, menstrual cycle phase was shown to possibly affect physical performance measures in female Rugby athletes; but large individual responses were observed, which suggests the need to consider the menstrual cycle at an individual level. The series of studies contained in this Thesis provide valuable information to practitioners seeking to maximise performance in female Rugby Sevens and serves as a platform to direct future research.

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Appendix A – Performance in the 1.2 km shuttle run test reflects fitness capacities in Rugby players

Sella FS, Hébert-Losier K, Beaven CM, McMaster DT, Harvey M, Gill ND. Performance in the 1.2 km shuttle run test reflects fitness capacities in Rugby players, *Journal of Australian Strength and Conditioning*, 29 (5), 7-14, 2021.

Abstract

The relationships between performance in the 1.2 km shuttle test (Bronco) with the Multistage Shuttle Run Test (MSRT) and Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) in Rugby players were investigated. Additionally, differences in Bronco, MSRT, and Yo-Yo IR1 scores between backs (B) and forwards (F), and Rugby codes were assessed. Data from professional players (23 Rugby Sevens and 133 Rugby Union) were analysed. All Rugby Sevens players performed the Bronco and MSRT, whereas Rugby Union players completed the Bronco and Yo-Yo IR1. The relationship between the Bronco and MSRT or Yo-Yo IR1 was quantified using Pearson's *r*, whereas differences between playing positions and codes were quantified using Hedges' g effect sizes (ES). Large correlations were observed between Bronco and MSRT (*r* = -0.57 and 0.53). Very large correlations were observed between Bronco and Yo-Yo IR1 (*r* = -0.74 and 0.71). Similar Bronco (B: 289 ± 10 s; F: 291 ± 10 s) and MSRT (B: 2470 ± 162 m; F: 2446 ± 236 m) scores were found in Rugby Sevens backs and forwards, while moderately better Bronco (B: 294 ± 15 s; F: 311 ± 21 s) and Yo-Yo IR1 (B: 1985 ± 367 m; F: 1627 ± 375 m) scores characterised Rugby Union backs (ES = -0.90 and 0.96). Small to moderately better Bronco scores were observed in Rugby Sevens compared to Rugby Union players (ES = -0.36 to -0.99). These results support the utility of the Bronco as a fitness test in Rugby. The low shared variance observed between the Bronco and the two other tests, however, indicates the scores derived from these tests (e.g., speed) are not interchangeable.

Introduction

Rugby is a team sport that relies on several physical qualities. Among these, possessing well-developed aerobic and anaerobic capacities have been shown to be beneficial for performance. In professional Rugby Union, a very large correlation (r = 0.75) was observed between players' aerobic capacities and total distance covered during games (Swaby et al., 2016). Furthermore, moderate to very large correlations were reported between fitness capacities and on-field running activities in women's Rugby Sevens (Clarke et al., 2017b; Clarke et al., 2014; Vescovi & Goodale, 2015). Given the high-intensity intermittent nature of Rugby, possessing greater aerobic capacities seems advantageous for minimising fatigue and promoting recovery between repeated high-intensity bouts, as well as between matches (Ross et al., 2014; Stone & Kilding, 2009; Tomlin & Wenger, 2001).

In individual and team sports, a variety of physical tests are commonly used to assess the fitness capacities of athletes. Controlled laboratory-based treadmill running tests provide a more accurate measure of aerobic fitness (Williams & Kendall, 2007), however their use in team sport is limited due to the implementation of single athlete testing protocols and the subsequent time required to test a large number of athletes. For these reasons, several field tests have been developed and validated as practical alternatives to assess fitness capacities in team sport athletes (Impellizzeri et al., 2005). These tests require minimal equipment and expertise and allow for the testing of multiple athletes simultaneously on the training field. Among these physical tests, the Multistage Shuttle Run Test (MSRT) (Gabbett, 2000, 2002, 2005; Ross et al., 2015c; Waldron et al., 2014) and the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) (Atkins, 2006; Clarke et al., 2017b; Clarke et al., 2014; Darrall-Jones et al., 2015, 2016b; Dobbin et al., 2018a; Gabbett & Seibold, 2013; Higham et al., 2013; Jones et al., 2016; Vescovi

& Goodale, 2015) have been widely used in Rugby-related research to assess and describe the fitness capacities of players. Both tests are practical in applied settings and consist of 20-m shuttle runs at increasing intensities. The MSRT is a continuous shuttle test, whereas the Yo-Yo IR1 is interspersed with a brief recovery period following each shuttle. The MSRT was originally developed by Léger and Lambert (1982) with the aim to predict maximal aerobic power ($\dot{V}O2$ max), whereas the Yo-Yo IR1 was developed to evaluate the ability to repeatedly perform high-intensity work in intermittent sports (Bangsbo et al., 2008).

Another popular field-based fitness test in Rugby is the 1.2 km shuttle run test also known as the "Bronco". This test is often used by practitioners as it is time-efficient, easy to administer, and requires minimal equipment. The protocol consists of a continuous 20, 40, and 60 m shuttle run, completed five times at a maximal intensity (i.e., 20 m and back, 40 m and back, 60 m and back) (Kelly & Wood, 2013). Despite the widespread use of the Bronco in Rugby, very limited research exists on this test. One investigation has demonstrated a high test-retest reliability based on intraclass correlation coefficient (ICC) of 0.99 and Bland-Altman 95% limits of agreements of 0.45 ± 5.2 s (Brew & Kelly, 2014). Furthermore, previous research has reported very large to almost perfect correlations and shared variance (R^2 = 0.73-0.93) between performance in the Bronco and performance in the 30-15 Intermittent Fitness Test (30-15 IFT) in male Rugby League and Netball players (Kelly & Wood, 2013), and very large correlations (r = -0.89) between the Bronco with the Yo-Yo IR1 in young male Rugby Union players (Deuchrass et al., 2019). One additional study (Kelly et al., 2014) has also described the Bronco scores of athletes competing in various team sports (e.g., Rugby Union, Rugby League), at different playing levels, and age groups. However, no comparisons were conducted between these categories.

To our knowledge, no study has examined the relationship between the Bronco and other fitness tests in professional Rugby players. Therefore, the primary aim of this study was to investigate the relationship between the Bronco test with the MSRT and the Yo-Yo IR1 in Rugby Sevens and Rugby Union players. A second aim was to provide information and examine the differences in Bronco, MSRT, and Yo-Yo IR1 performance between playing positions (i.e., backs and forwards) and Rugby codes (i.e., Rugby Sevens and Rugby Union).

Methods

Approach to the problem

The relationship between performance in the Bronco with performance in the MSRT and Yo-Yo IR1 was examined using a descriptive correlation design. In particular, the correlation coefficients between Bronco (time and average speed) with MSRT (distance and final speed) and Yo-Yo IR1 (distance and final speed) measures were investigated. To evaluate the differences in Bronco, MSRT, and Yo-Yo IR1 performance between playing positions and Rugby codes, comparisons were conducted between backs and forwards, and between Rugby Sevens and Rugby Union players.

Participants

Data from 23 professional male Rugby Sevens players and 133 professional male Rugby Union players were included in the analysis. All Rugby Sevens players were playing Internationally in the World Rugby Sevens Series representing their National team. All Rugby Union players were competing in Super Rugby, 47 players were also playing for their National teams at the time of testing. The data included 63 trials performed by Rugby Sevens players and 274 trials performed by Rugby Union players given that certain players were assessed on multiple occasions. Approval was granted from Auckland University of Technology Research Ethics Committee.

Procedures

Participants completed the fitness tests at various times between 2015 and 2019. Each participant performed two different fitness tests on two separate occasions, in a randomised order, within four consecutive weeks. All Rugby Sevens players completed the Bronco and MSRT, whereas Rugby Union players completed the Bronco and Yo-Yo IR1. All tests were performed outdoors on grass in Rugby boots following a 15-minute warm up consisting of jogging, dynamic stretches, and stride outs. Players were familiar with the tests and were instructed to give a maximal effort. Strong verbal encouragement was given throughout the tests.

1.2 km shuttle run test (Bronco)

The Bronco was conducted in agreement with the protocol described by Kelly and Wood (2013). The test consists of a continuous 20, 40, and 60 m shuttle run, completed five times at a maximal intensity as shown in Figure 8. Time to complete the test and average running speed, calculated from total time, were used for analysis. Excellent test-retest relative reliability of Bronco total times (ICC = 0.99) has been reported (Brew & Kelly, 2014).

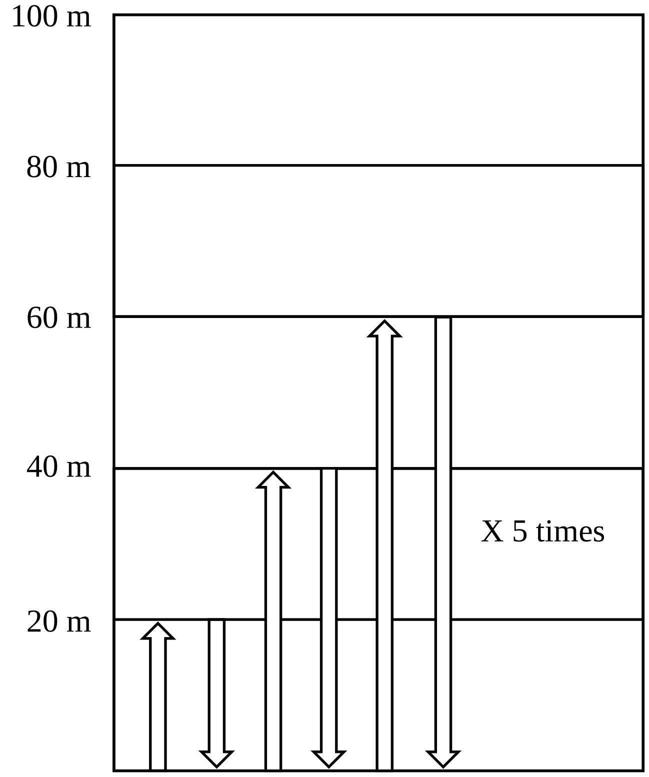

Figure 8. Bronco test protocol

Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1)

The Yo-Yo IR1 consists of 2 x 20 m shuttle runs at progressively increasing speeds, interspersed with 10 seconds of active rest controlled by audio signal (Bangsbo et al., 2008; Krustrup et al., 2003). The test starts at a running speed of 10 km·h^{-1} and continues until each player attains volitional exhaustion. Specifically, the test was terminated when the athletes failed to reach the finishing line in the allotted time on two occasions, with a verbal warning given following the first failure. Total distance covered and final running speed, defined as the speed attained during the last completed stage, were considered for analysis. Acceptable test-retest absolute reliability for total distance covered during the Yo-Yo IR1 has been reported (coefficient of variation = 4.9%) (Krustrup et al., 2003).

Multistage Shuttle Run Test (MSRT)

The MSRT was performed as described by Léger and Gadoury (1989). The test consists of continuous shuttle runs over 20 m at progressively increasing speeds determined by an audio signal. Starting speed was set at 8 $km \cdot h^{-1}$ for the first minute, increasing by 0.5 $km \cdot h^{-1}$ every minute thereafter. The test ended when a player was no longer able to perform a shuttle in the required time. Total distance covered and final running speed, defined as the speed attained during the last completed stage, were included in the analysis. Excellent test-retest reliability for the MSRT predicted $\dot{V}O2$ max (Pearson's correlation coefficient, r = 0.975) has been reported (Léger & Lambert, 1982).

Statistical analysis

Since multiple testing results from the same athlete were analysed, generalised estimating equations (GEE) with a dependent (AR1) correlation structure were used (Liang & Zeger, 1986). GEE allow for longitudinal or repeated measurements analysis with non-normal response variables and incomplete data sets (Ballinger, 2004). MSRT or Yo-Yo IR1 scores (distance or final speed) were entered in the GEE model as a dependent variable, while Bronco score (time or average speed) was used as the predictor. To assess the relationship between fitness tests, Pearson's correlation coefficient (r) with 95% confidence intervals [lower, upper] was calculated between the dependent variable and the value predicted from the GEE model. The magnitude of correlations was interpreted using the following thresholds: r<0.1 trivial, r<0.3 small, r<0.5 moderate, r<0.7 large, r<0.9 very large, and $r \geq 0.9$ extremely large (Hopkins et al., 2009). Statistical significance was set at $p \leq 0.05$. To evaluate differences in Bronco performance between playing positions and Rugby codes Hedges' g effect size (ES) with 95% confidence intervals [lower, upper] was calculated. ES magnitudes were interpreted as g<0.2 trivial, g<0.6 small, g<1.2 moderate, g<2.0 large, g<4.0 very large, and g≥4.0 extremely large.

If the 95% CI overlapped small positive and negative values, the magnitude of the correlation or the ES was deemed unclear (Hopkins et al., 2009). All statistical analysis were conducted using SPSS (Version 25; IBM Corporation, New York, 180 USA).

Results

Average Bronco, MSRT, and Yo-Yo IR1 scores of Rugby Sevens and Rugby Union players are reported in Table 16. The parameter estimates of the GEE model for MSRT and Yo-Yo IR1 speed are presented in Table 17 resulting in the following equations:

$$\text{MSRT final speed} = 2.266 + (0.424 \times \text{Bronco average speed})$$

$$\text{Yo-Yo IR1 final speed} = 2.499 + (0.515 \times \text{Bronco average speed})$$

Table 16. Bronco, MSRT, and Yo-Yo IR1 scores. Values are mean ± SD and range.

Variable	Rugby Sevens (*n* = 63 trials)	Rugby Union (*n* = 274 trials)
Bronco time (s)	290 ± 10 (267–313)	304 ± 20 (267–370)
Bronco average speed ($m \cdot s^{-1}$)	4.15 ± 0.14 (3.83–4.49)	3.97 ± 0.25 (3.24–4.49)
MSRT distance (m)	2462 ± 189 (2020–2940)	--
MSRT final speed ($m \cdot s^{-1}$)	4.03 ± 0.11 (3.75–4.31)	--
Yo-Yo IR1 distance (m)	--	1772 ± 411 (680–2720)
Yo-Yo IR1 final speed ($m \cdot s^{-1}$)	--	4.54 ± 0.19 (4.03–5.00)

MSRT = Multistage Shuttle Run Test, Yo-Yo IR1 = Yo-Yo Intermittent Recovery Test Level 1

Table 17. Parameter estimates from GEE analysis for MSRT and Yo-Yo IR1 speed from Bronco speed.

	B	SE	95% Wald CI		Wald Chi-Square	df	*P*-value
			Lower	Upper			
MSRT final speed							
Intercept	2.266	0.340	1.599	2.933	44.35	1	*P* < 0.001
Bronco average speed	0.424	0.827	0.262	0.586	26.32	1	*P* < 0.001
Yo-Yo IR1 final speed							
Intercept	2.499	0.140	2.224	2.774	317.56	1	*P* < 0.001
Bronco average speed	0.515	0.355	0.445	0.585	210.24	1	*P* < 0.001

CI = Confidence interval, df = degrees of freedom, GEE = Generalised estimating equations, MSRT = Multistage Shuttle Run Test, SE = Standard error, Yo-Yo IR1 = Yo-Yo Intermittent Recovery Test Level 1

Large correlations were observed between Bronco time and average speed with MSRT distance and final speed, respectively (Table 18). Very large correlations were observed between Bronco time and average speed with Yo-Yo IR1 distance and final speed, respectively (Table 18). All correlations were significant and clear.

Bronco scores specific to playing position and Rugby code are presented in Table 19. Unclear differences were found between backs and forwards in professional male Rugby Sevens players; whereas moderately better Bronco scores were found in professional Rugby Union backs compared to forwards. Small to moderately better Bronco performance characterised professional Rugby Sevens players compared to professional Rugby Union players (Table 19).

Table 18. Correlations between Bronco and MSRT, or Yo-Yo IR1. Values are Pearson's *r* and 95% confidence intervals [lower, upper].

Bronco	MSRT		Yo-Yo IR1	
	Distance (m)	Final speed ($m \cdot s^{-1}$)	Distance (m)	Final speed ($m \cdot s^{-1}$)
Time (s)	-0.57*L [-0.71, -0.37]		-0.74*V [-0.79, -0.68]	
Average speed ($m \cdot s^{-1}$)		0.53*L [0.32, 0.68]		0.71*V [0.65, 0.76]

MSRT = Multistage Shuttle Run Test, Yo-Yo IR1 = Yo-Yo Intermittent Recovery Test Level 1.
* $p < 0.01$.
L large, V very large.

Table 19. Bronco times (s) of Rugby Sevens and Rugby Union players specific to playing position. Values are mean ± SD, ES and 95% confidence intervals [lower, upper].

	Backs	Forwards	ES [CI]
Rugby Sevens	289 ± 10 (*n* = 41 trials)	291 ± 10 (*n* = 22 trials)	-0.20 [-0.72, 0.32]
Rugby Union	294 ± 15 (*n* = 112 trials)	311 ± 21 (*n* = 162 trials)	-0.90M [-1.15, -0.65]
ES [CI]	-0.36S [-0.72, 0.00]	-0.99M [-1.45, -0.54]	

CI = Confidence interval, ES = Effect size.
S small, M moderate.

MSRT and Yo-Yo IR1 results specific to playing position are reported in Table 20. Unclear differences were observed between professional Rugby Sevens backs and forwards in the MSRT; whereas moderately better Yo-Yo IR1 scores were observed in professional Rugby Union backs compared to forwards (Table 20).

Table 20. MSRT and Yo-Yo IR1 distances (m) of Rugby Sevens and Rugby Union players specific to playing position. Values are mean ± SD, ES and 95% confidence intervals [lower, upper].

	Backs	Forwards	ES [CI]
MSRT, Rugby Sevens	2470 ± 162 (*n* = 41 trials)	2446 ± 236 (*n* = 22 trials)	0.12 [-0.39, 0.64]
Yo-Yo IR1, Rugby Union	1985 ± 367 (*n* = 112 trials)	1627 ± 375 (*n* = 162 trials)	0.96[M] [0.71, 1.21]

CI = Confidence intervals, ES = Effect size, MSRT = Multistage Shuttle Run Test, Yo-Yo IR1 = Yo-Yo Intermittent Recovery Test Level 1.
[M] moderate.

Discussion

The large to very large correlations observed between Bronco with the MSRT and Yo-Yo IR1 in professional male Rugby players were clear and significant. Similar Bronco and MSRT scores were observed between backs and forwards in professional Rugby Sevens players, while better Bronco and Yo-Yo IR1 scores were observed in professional Rugby Union backs compared to forwards. Further, better Bronco scores were found in professional Rugby Sevens players compared to professional Rugby Union.

Current findings are in agreement with the study of Deuchrass et al. (2019) that showed a very large correlation (r = -0.87) between Bronco time and distance covered in the Yo-Yo IR1 in young male Rugby Union players. The slight difference in the correlation coefficients observed between the studies (r = -0.87 and -0.74) is likely attributed to the different populations considered (i.e., professional vs young players) and differing sample sizes. In the current study, a very large correlation was observed between Bronco average running speed (3.97 $m \cdot s^{-1}$) with final running speed attained in the Yo-Yo IR1 (4.54 $m \cdot s^{-1}$) in professional Rugby Union players; whereas a large correlation was observed between Bronco average speed (4.15 $m \cdot s^{-1}$) with final running speed attained in the MSRT (4.03 $m \cdot s^{-1}$) in professional Rugby Sevens players. The relatively low shared variance (28 to 50%) observed in the running speed between the Bronco with the MSRT and Yo-Yo IR1, indicates that there are other contributing factors to performance in these tests, and the speeds obtained in the different tests are not interchangeable. The different testing protocols and variables analysed likely explain these results. In fact, while the MSRT and Yo-Yo IR1 speeds represent the final speed reached during an incremental test, the Bronco speed is the average speed derived from a distance-based test. Furthermore, while Bronco speeds were obtained over a ~ 5 min-test in professional Rugby Sevens and Rugby Union players, on average the MSRT and Yo-Yo IR1 took ~ 13 and 14 min to completion, respectively.

Of note, a greater degree of correlation ($R^2 = 0.73$) was found between Bronco average running speed with the final speed recorded in the 30-15 IFT in semi-professional male Rugby League players (Kelly & Wood, 2013), compared with the final speeds obtained in the MSRT and Yo-Yo IR1. Despite being continuous, greater correlations were observed between the Bronco and intermittent shuttle tests (i.e., 30-15 IFT (Kelly & Wood, 2013) and Yo-Yo IR1), compared with the continuous MSRT. However, knowledge of the specific physiological responses (e.g., heart rate, $\dot{V}O2$ max, and blood lactate) to the different tests in Rugby players would be required for more detailed comparisons to be made.

In addition to assessing physical performance, fitness tests are used to inform exercise prescription and determine appropriate training intensities. Maximal aerobic speed (MAS), defined as the lowest speed that elicits $\dot{V}O2$ max (Billat & Koralsztein, 1996), has been widely employed as a reference speed to prescribe training intensity in different sports. Gas analysers are the only method able to provide a true measure of MAS or v$\dot{V}O2$ max (Buchheit, 2010).

Nevertheless, given the difficulties of conducting laboratory $\dot{V}O2$ max testing in team sports, a number of field-based tests have been developed and proposed as a practical alternative to indirectly predict MAS (Bellenger et al., 2015; Paradisis et al., 2014). In addition to MAS, the final speed reached during the 30-15 IFT has been suggested as a reference speed to establish exercise intensity. In particular, when exercise consists of intermittent shuttle runs, 30-15 IFT final speed appears to be a more accurate reference to prescribe training intensities compared to MAS (Buchheit, 2008). With regards to the Bronco, a practical correction equation has been proposed to prescribe exercise intensities based on the time taken to complete the test (Baker & Heaney, 2015). Given the very large correlations observed between Bronco and 30-15 IFT speeds (R^2 = 0.73 to 0.93), Kelly and Wood (2013) suggested that a correction factor could be applied starting from the 30-15 IFT speed. However, due to the lack of scientific evidence, future research is warranted to investigate the relationship between Bronco measures with the gold-standard laboratory tests (i.e., gas analysis and physiological responses), and the ability of the Bronco to inform exercise prescription and set training intensities for Rugby players and other team sports.

The ability of a test to reflect the specific demands of a given sport needs to be considered when choosing a fitness test (Clarke et al., 2014). Specific to Rugby, a very large correlation (r = 0.75) was observed between a 1.2 km time trial performance performed on a grass-field track and total distance covered during games in professional male Rugby Union players (Swaby et al., 2016). Furthermore, moderate to large correlations were observed between performance in the Yo-Yo IR1 and on-field running activities in women's Rugby Sevens (Clarke et al., 2017b; Clarke et al., 2014; Vescovi & Goodale, 2015). Like Rugby, the Bronco consists of multiple accelerations, decelerations, and changes of direction. Additionally, the heart rate and blood lactate values recorded post-test suggest that the Bronco stresses both the aerobic and anaerobic systems (Brew & Kelly, 2014). However, further research is required to assess the relationship between Bronco performance (e.g., time and average speed) with match demands metrics (e.g., total distance and high-intensity distance) in Rugby and other team sports.

This study is the first to report and examine Bronco scores of professional Rugby Sevens and Rugby Union players specific to playing position. Similar Bronco performance were observed between backs and forwards in Rugby Sevens players; whereas substantially better performance was observed in Rugby Union backs compared with forwards. Analogous results were observed when comparing MSRT and Yo-Yo IR1 performance between playing positions in Rugby Sevens and Rugby Union, respectively. Thus, suggesting that the tests possess a similar sensitivity in detecting fitness performance differences between playing positions. During international-level men's Rugby Sevens matches, trivial to small differences were reported between playing positions in the running activities (Higham et al., 2016; Ross et al., 2015b), with maximal velocity showing a moderate difference (Ross et al., 2015b) between backs and forwards; therefore, it is apparent that well-developed fitness capacities are important to both backs and forwards (Ross et al., 2015d). It is possible that the lack of positional differences observed in the Bronco and MSRT reflect the similar running activities of backs and forwards during international-level games. In contrast to Rugby Sevens, the greater running demands of professional Rugby Union backs (Cahill et al., 2013; Quarrie et al., 2013; Roberts et al., 2008; Swaby et al., 2016) compared with forwards are likely to explain their superior performance in the Bronco and Yo-Yo IR1.

Between Rugby codes, slightly better Bronco performance was observed in Rugby Sevens backs compared with Rugby Union backs and moderately better scores characterised Rugby

Sevens forwards compared to their Rugby Union counterparts. Given the reduced number of players competing on a full-size rugby pitch and the relatively short duration of the games, higher running demands and intensities have been observed in international-level Rugby Sevens matches compared to professional Rugby Union matches (Higham et al., 2013; Ross et al., 2014). These different match demands suggest the need to possess high levels of aerobic and anaerobic capacities. In addition, since professional Rugby Sevens players are often required to compete in up to six matches over two days, possessing well-developed aerobic capacities seems to be beneficial for recovery between matches (Ross et al., 2014). Of note, the larger difference observed between Rugby Sevens and Union forwards compared with backs is likely correlated to the higher specialisation of Rugby Union forwards compared to Rugby Sevens. Professional Rugby Sevens players are required to complete in more similar tasks, as suggested by the more similar running and match activities between playing positions (Higham et al., 2013; Ross et al., 2015b). In contrast, professional Rugby Union forwards show a greater involvement in contact situations (e.g., scrums, rucks, and tackles) when compared to backs who engage in a greater number of high-intensity running activities (Quarrie et al., 2013).

The professional Rugby Union players included in this study displayed Bronco times and average speeds of 304 ± 20 s and 3.97 ± 0.25 $m \cdot s^{-1}$, respectively. Kelly et al. (2014), reported slightly slower Bronco times (311 ± 28 s, Δ% = 2.3%) and average speeds (3.86 ± 0.34 $m \cdot s^{-1}$, Δ% = 2.8%) in professional Rugby Union players. Two other studies investigating Bronco performance in professional Rugby Union players reported Bronco times between 297 – 302 s (Mayo et al., 2018), and 297 – 316 s (Miles et al., 2019), respectively. When Bronco times were categorised by playing position, as expected backs (294 ± 15 s) were faster than forwards (311 ± 21 s). The study of Deuchrass et al. (2019) investigating fitness qualities in young Rugby Union players (Age: 19 ± 1 years) recorded Bronco times of 284 ± 11 s, 297 ± 8 s, 317 ± 15 s, and 301 ± 13 s for inside backs, outside backs, tight forwards and loose forwards, respectively. These results suggest that Bronco performance is similar (Δ% = 0.6-1.0%) between professional and young players. A previous investigation conducted in Rugby Union players has shown that fitness capacities measured via the 30-15 IFT are similar between academy and professional players when expressed in absolute terms (Darrall-Jones et al., 2016a). However, the substantial increase in body mass observed from academy to senior players and its potential detrimental effect on testing performance could mask any improvements, if fitness scores are expressed without considering body mass (Darrall-Jones et al., 2016a).

Practical applications

Clear and significant correlations were observed between performance in the Bronco with performance in the MSRT and Yo-Yo IR1 in professional Rugby players. However, test scores (e.g., average and final shuttle speed) derived from these tests should not be used interchangeably given the low shared variance between tests. The Bronco displayed a similar sensitivity compared with the MSRT and Yo-Yo IR1 in detecting fitness performance differences between playing positions in Rugby players. Similar Bronco and MSRT results were observed between professional Rugby Sevens backs and forwards, possibly due to the homogeneity of running activities during games. In contrast, the greater running demands observed in professional Rugby Union backs compared to forwards most likely explain the differences Bronco and Yo-Yo IR1 performance between positions. The clear differences observed in Bronco performance between Rugby codes highlight the different on-field demands of these Rugby codes.

When deciding the most appropriate fitness test to use, a number of variables should be considered, including time to administer, the number of players being tested, test characteristics (i.e., specificity, validity, reliability, and sensitivity), and its purpose (e.g., monitoring fitness levels and/or prescribing individualised fitness training intensities). The Bronco test is easy to administer, requires minimal time and equipment, and is reliable (Brew & Kelly, 2014); however, it requires at least 60 m of space to be completed. In contrast, the MSRT and Yo-Yo IR1 require more time and an audio signal to be performed; however, they only need 20-25 m of space. Overall, these results provide support for the use of the Bronco as a viable fitness test for Rugby players.

Appendix B. Appendices for Chapter 2

Appendix B1. Study quality assessment

For the purpose of this review, the following modifications to the original 27-items Downs and Black Quality Assessment Checklist were applied. The term “patient” was replaced with “participant”, and “treatment” with “testing”. On questions 8, 10, 14, 15, 17, 19, 23, 24, 26, and 27, ‘‘Not applicable’’ was added as a scoring option. For questions 5 and 25, country of origin, playing level, playing position (backs and forwards), and information regarding the type (menstrual or contraceptive) and phase (high or low hormones) of the cycle of participants at the moment of testing were considered as confounding variables. To receive two points on question 5, all four confounders had to be reported. For one point, two or three confounders had to be addressed. A score of zero was given when one or no confounder was given. When no participants were lost to follow-up, when losses to follow-up were < 10%, or when at least 90% of the total cohort completed all assessments, questions 9 and 26 were scored “Yes”. Question 11 was answered “Yes” if all the athletes of a given team were invited to participate, whereas question 12 was answered “Yes” when all the athletes of a given team participated in the study. When an article reported or provided a reference to the accuracy of a measurement system, question 20 was scored ‘‘Yes’’. Question 27 was scored “Yes” when statistical significance was reached or the effect size was clear, “No” when statistical significance was not reached or the effect size was unclear, and “Not applicable” when no statistical analysis was performed (e.g., observational study with no comparisons).

Appendix B2. Modified Downs and Black quality assessment checklist and quality score

	Agar-Newman et al., 2017	Clarke et al., 2014	Clarke et al., 2015c	Clarke et al., 2015a	Clarke et al., 2015b	Clarke et al., 2017b	Clarke et al., 2017a	Clarke et al., 2017c	Del Coso et al., 2013
Reporting									
1. Aims clearly described	✓	✓	✓	✓	✓	✓	✓	✓	✓
2. Main outcome to be measured clearly described	✓	✓	✓	✓	✓	✓	✓	✓	✓
3. Participants characteristics clearly described	✓	✓	✓	✓	✓	✓	✓	✓	✓
4. Interventions of interest clearly described	✓	✓	✓	✓	✓	✓	✓	✓	✓
5. Principal confounders clearly described	✓	✓	✓	✓	✓	✓	✓	X	✓
6. Main findings clearly described	✓	✓	✓	✓	✓	✓	X	✓	✓
7. Estimate of random variability provided	✓	✓	✓	✓	✓	✓	✓	X	✓
8. Important adverse events of the intervention reported	X	X	X	X	X	X	X	NA	✓
9. Characteristics of participants lost to follow-up described	X	✓	X	X	X	X	X	✓	✓
10. Probabilities values reported	✓	X	X	X	X	X	X	NA	X
External Validity									
11. Subjects asked to participate representative of population	U	U	U	U	U	U	U	U	U
12. Subjects prepared to participate representative of population	U	U	U	U	U	U	U	U	U
13. Location and delivery of testing representative of population	✓	✓	✓	✓	✓	U	U	✓	U
Internal Validity – Bias									
14. Participants blinded to intervention	NA	NA	NA	NA	NA	NA	NA	NA	✓
15. Investigators blinded to intervention	U	NA	U	NA	U	U	U	U	✓
16. Any "data dredging" clearly described	✓	✓	✓	✓	✓	✓	X	✓	✓
17. Analysis adjusted for different lengths of follow-up	NA	NA	✓	NA	X	NA	✓	NA	✓
18. Appropriate statistical tests performed	✓	✓	✓	✓	✓	✓	✓	✓	✓
19. Compliance with the interventions reliable	NA	NA	NA	NA	NA	NA	NA	NA	✓
20. Outcome measures valid and reliable	✓	✓	✓	✓	U	✓	✓	✓	✓
Internal Validity – Confounding									
21. Participants recruited from the same population	✓	✓	✓	✓	✓	✓	U	U	✓
22. Participants recruited over the same time period	✓	✓	✓	✓	✓	U	U	U	✓
23. Participants randomised to intervention	NA	NA	NA	NA	NA	NA	NA	NA	✓
24. Assignment concealed from investigators and participants	NA	NA	NA	NA	NA	NA	NA	NA	✓
25. Adequate adjustment for confounding	✓	X	✓	X	X	✓	X	X	X
26. Losses to follow-up taken into account	X	✓	X	X	X	X	X	NA	✓
Power									
27. Sufficient power to detect a significant and/or clear effect	✓	✓	✓	✓	✓	✓	✓	NA	✓
Overall score (*n*/*n* applicable)	16/23	16/22	16/24	14/22	13/24	13/23	10/24	10/19	22/28
Quality Index	70%	73%	67%	64%	54%	56%	42%	53%	79%
	M	M	M	M	M	M	L	M	S

✓✓ = two points, ✓ = one point, L = Limited, M = Moderate, NA = Not applicable, S = Strong, U = Unable to determine, X = zero points.

	Fuller et al., 2017	Gathercole et al., 2015	Goodale et al., 2016	Goodale et al., 2017	Griffin et al., 2017b	Griffin et al., 2017a	Leite et al., 2016	Ma et al., 2016	Malone et al., 2020
Reporting									
1. Aims clearly described	✓	✓	✓	✓	✓	✓	✓	✓	✓
2. Main outcome to be measured clearly described	✓	✓	✓	✓	✓	✓	✓	✓	✓
3. Participants characteristics clearly described	✓	✓	✓	✓	✓	✓	✓	X	✓
4. Interventions of interest clearly described	✓	✓	✓	✓	✓	✓	✓	✓	✓
5. Principal confounders clearly described	✓	X	X	✓	X	X	X	✓	✓
6. Main findings clearly described	✓	X	✓	✓	✓	✓	✓	✓	✓
7. Estimate of random variability provided	✓	✓	✓	✓	✓	✓	✓	✓	✓
8. Important adverse events of the intervention reported	NA	X	X	NA	NA	NA	X	NA	NA
9. Characteristics of participants lost to follow-up described	✓	X	X	✓	✓	X	✓	✓	✓
10. Probabilities values reported	✓	X	✓	✓	✓	✓	✓	✓	✓
External Validity									
11. Subjects asked to participate representative of population	✓	U	U	U	U	U	U	✓	✓
12. Subjects prepared to participate representative of population	✓	U	U	U	U	U	U	U	U
13. Location and delivery of testing representative of population	✓	U	✓	✓	✓	✓	U	✓	✓
Internal Validity – Bias									
14. Participants blinded to intervention	NA	NA	NA	NA	NA	NA	NA	NA	NA
15. Investigators blinded to intervention	NA	NA	NA	NA	NA	NA	NA	NA	NA
16. Any "data dredging" clearly described	✓	✓	✓	✓	✓	✓	✓	✓	✓
17. Analysis adjusted for different lengths of follow-up	✓	✓	U	NA	✓	✓	NA	✓	NA
18. Appropriate statistical tests performed	✓	✓	✓	✓	✓	✓	✓	✓	✓
19. Compliance with the interventions reliable	NA	NA	NA	NA	NA	NA	NA	NA	NA
20. Outcome measures valid and reliable	✓	U	✓	✓	✓	✓	U	✓	✓
Internal Validity – Confounding									
21. Participants recruited from the same population	✓	✓	✓	✓	✓	✓	✓	✓	✓
22. Participants recruited over the same time period	✓	✓	✓	✓	✓	✓	U	✓	✓
23. Participants randomised to intervention	NA	NA	NA	NA	NA	NA	NA	NA	NA
24. Assignment concealed from investigators and participants	NA	NA	NA	NA	NA	NA	NA	NA	NA
25. Adequate adjustment for confounding	X	X	X	✓	X	X	X	✓	✓
26. Losses to follow-up taken into account	✓	X	X	✓	✓	X	NA	✓	✓
Power									
27. Sufficient power to detect a significant and/or clear effect	✓	✓	✓	✓	✓	✓	✓	✓	✓
Overall score (*n*/*n* applicable)	20/22	11/23	14/23	18/21	17/22	15/22	12/21	19/22	19/21
Quality Index	91%	48%	61%	86%	78%	68%	57%	86%	90%
	S	L	M	S	S	M	M	S	S

✓✓ = two points, ✓ = one point, L = Limited, M = Moderate, NA = Not applicable, S = Strong, U = Unable to determine, X = zero points.

	Misseldine et al., 2021	Ohya et al., 2015	Portillo et al., 2014	Portillo et al., 2017	Reyneke et al., 2018	Mirsafaei Rizi et al., 2017	Suárez-Arrones et al., 2012	Valenzuela et al., 2018	Vescovi & Goodale, 2015
Reporting									
1. Aims clearly described	✓	✓	✓	✓	✓	✓	✓	✓	✓
2. Main outcome to be measured clearly described	✓	✓	✓	✓	✓	✓	✓	✓	✓
3. Participants characteristics clearly described	✓	✓	✓	✓	✓	✓	✓	✓	X
4. Interventions of interest clearly described	✓	✓	✓	✓	✓	✓	✓	✓	✓
5. Principal confounders clearly described	✓	✓	✓	✓	X	✓	X	X	✓
6. Main findings clearly described	✓	✓	✓	✓	✓	✓	✓	✓	✓
7. Estimate of random variability provided	✓	✓	✓	✓	✓	✓	✓	✓	✓
8. Important adverse events of the intervention reported	NA	X	NA	✓	NA	X	X	X	X
9. Characteristics of participants lost to follow-up described	✓	X	✓	✓	✓	✓	✓	✓	X
10. Probabilities values reported	X	X	X	✓	X	✓	X	X	✓
External Validity									
11. Subjects asked to participate representative of population	U	U	U	U	U	U	U	✓	U
12. Subjects prepared to participate representative of population	U	U	U	U	U	U	U	✓	U
13. Location and delivery of testing representative of population	✓	✓	✓	✓	✓	✓	U	U	U
Internal Validity – Bias									
14. Participants blinded to intervention	NA	NA	NA	✓	NA	NA	NA	NA	NA
15. Investigators blinded to intervention	NA	NA	NA	✓	U	NA	NA	U	U
16. Any "data dredging" clearly described	✓	✓	✓	✓	✓	✓	✓	X	✓
17. Analysis adjusted for different lengths of follow-up	NA	NA	NA	✓	NA	✓	NA	NA	NA
18. Appropriate statistical tests performed	✓	✓	✓	✓	✓	✓	✓	✓	✓
19. Compliance with the interventions reliable	NA	NA	NA	✓	NA	NA	NA	NA	NA
20. Outcome measures valid and reliable	✓	U	✓	✓	✓	✓	✓	✓	✓
Internal Validity – Confounding									
21. Participants recruited from the same population	✓	✓	✓	✓	✓	✓	✓	✓	✓
22. Participants recruited over the same time period	✓	✓	✓	✓	✓	✓	✓	✓	✓
23. Participants randomised to intervention	NA	NA	NA	✓	NA	NA	NA	NA	NA
24. Assignment concealed from investigators and participants	NA	NA	NA	✓	NA	NA	NA	NA	NA
25. Adequate adjustment for confounding	✓	✓	X	X	X	X	X	X	X
26. Losses to follow-up taken into account	U	X	✓	✓	✓	✓	✓	✓	X
Power									
27. Sufficient power to detect a significant and/or clear effect	✓	✓	✓	✓	✓	✓	✓	✓	✓
Overall score (*n*/*n* applicable)	16/21	14/22	16/21	24/28	15/21	18/23	14/22	15/23	13/23
Quality Index	76%	64%	76%	86%	71%	78%	64%	65%	57%
	S	M	S	S	M	S	M	M	M

✓✓ = two points, ✓ = one point, L = Limited, M = Moderate, NA = Not applicable, S = Strong, U = Unable to determine, X = zero points.

Appendix B3. GPS match data of female Rugby Sevens athletes

Article	Comp	Device, no. files	Total match distance (m)	Relative match distance (m·min^{-1})	Sprints/ Accel (*n*)	Max speed (m·s^{-1})	Distance covered per speed zone				
							0 m·s^{-1}	2.2 m·s^{-1}	3.5 m·s^{-1}	5.0 m·s^{-1}	5.5 m·s^{-1}
Clarke et al., 2017b	Int (WS)	GPS[a] 5 Hz, 89 T		T: 86 ± 4		T: 8.1 ± 0.6					
Del Coso et al., 2013	Int	GPS[b] 5 Hz, 28 P 28 ED		P: 88 ± 8 ED: 95 ± 13						*5.0-5.5 m·s^{-1}* P: 3.7 ± 1.4 m·min^{-1} ED: 4.4 ± 1.4 m·min^{-1}	*>5.5 m·s^{-1}* P: 4.6 ± 3.3 m·min^{-1} ED: 6.1 ± 3.4 m·min^{-1}
Goodale et al., 2017	Int (WS)	GPS[c] 10 Hz, 191 T 103 B 88 F 193 FH 216 SH		T: 87 ± 11 B: 86 ± 9 F: 87 ± 12		T: 6.9 ± 0.8 B: 7.1 ± 0.7 F: 6.7 ± 0.7 FH: 6.6 ± 0.9 SH: 6.5 ± 0.8	*0-0.2 m·s^{-1}* T: 2 ± 1 m·min^{-1} B: 2 ± 1 m·min^{-1} F: 2 ± 1 m·min^{-1}	*0.2-3.5 m·s^{-1}* T: 59 ± 7 m·min^{-1} B: 59 ± 7 m·min^{-1} F: 59 ± 8 m·min^{-1}	*3.5-5.0 m·s^{-1}* T: 16 ± 5 m·min^{-1} B: 15 ± 5 m·min^{-1} F: 18 ± 6 m·min^{-1}	*5.0-6.5 m·s^{-1}* T: 7 ± 3 m·min^{-1} B: 8 ± 3 m·min^{-1} F: 7 ± 3 m·min^{-1}	*≥6.5 m·s^{-1}* T: 2 ± 2 m·min^{-1} B: 2 ± 2 m·min^{-1} F: 2 ± 2 m·min^{-1}
Malone et al., 2020	Int (WS)	GPS[d] 10 Hz, 250 T 131 B 119 F	T: 1625 ± 132 B: 1728 (1422-1865) F: 1422 (1123-1468) FH: 865 SH: 765	T: 116 ± 9	*Sprints* B: 4.5 (1.4-5.1) F: 2.5 (1.0-3.1) *Accel* B: 14 (10-16) F: 11 (9-13)	T: 7.5 ± 1.4 B: 7.7 (7.3- 8.2) F: 7.5 (7.0-8.0) FH: 7.6 SH: 7.5				*4.4-5.5 m·s^{-1}* T: 199 ± 44 m, 14.2 ± 3.1 m·min^{-1} B: 223 m (195-254) F: 174 m (104-200) FH: 107 m SH: 93 m	*≥5.5 m·s^{-1}* T: 118 ± 45 m B: 133 m (130-143) F: 102 m (98-111) FH: 63 m SH: 55 m
Misseldine et al., 2021	Int	GPS[e] 5 Hz, 59 T 19 B 12 F		T: 98 ± 8 B: 98 ± 8 F: 97 ± 6		T: 7.0 ± 0.7 B: 7.5 ± 0.7 F: 6.7 ± 0.5					

Article	Comp	Device, no. files	Total match distance (m)	Relative match distance (m·min^{-1})	Sprints/ Accel (n)	Max speed (m·s^{-1})	Distance covered per speed zone					
							0 m·s^{-1}	2.2 m·s^{-1}	3.5 m·s^{-1}		5.0 m·s^{-1}	5.5 m·s^{-1}
Portillo et al., 2014	Int	GPS[b] 15 Hz, 29 T 36 FH 30 SH	T: 1642 ± 171 FH: 883 ± 122 SH: 725 ± 157		*Sprints* T: 6.1 ± 3.1 *Accel* FH: 6.0 ± 2.7 SH: 4.9 ± 2.4	T: 6.9 ± 0.5 FH: 6.8 ± 0.6 SH: 6.9 ± 0.4	*0-1.7 m·s^{-1}* T: 496 ± 69 m FH: 238 ± 34 m SH: 261 ± 46 m	*1.7-3.5 m·s^{-1}* T: 549 ± 74 m FH: 306 ± 48 m SH: 241 ± 63 m	*3.5-3.9 m·s^{-1}* T: 165 ± 44 m FH: 91 ± 29 m SH: 73 ± 22 m	*3.9-5.0 m·s^{-1}* T: 275 ± 88 m FH: 135 ± 45 m SH: 114 ± 50 m	*5.0-5.5 m·s^{-1}* T: 103 ± 48 m FH: 52 ± 24 m SH: 46 ± 19 m	*>5.5 m·s^{-1}* T: 119 ± 61 m FH: 62 ± 38 m SH: 62 ± 38 m
Suarez-Arrones et al., 2012	Int	GPS[f] 1 Hz, 17 T 17 FH 17 SH	T: 1556 ± 189		*Sprints* FH: 2.5 ± 1.6 SH: 2.8 ± 1.6	T: 6.4 ± 0.5 FH: 6.4 ± 0.6 SH: 6.4 ± 0.4	*0-1.7 m·s^{-1}* T: 463 ± 95 m	*1.7-3.5 m·s^{-1}* T: 516 ± 89 m	*3.5-3.9 m·s^{-1}* T: 181 ± 61 m	*3.9-5.0 m·s^{-1}* T: 256 ± 88 m	*5.0-5.5 m·s^{-1}* T: 57 ± 41 m	*>5.5 m·s^{-1}* T: 84 ± 65 m
Reyneke et al., 2018	Int (WS)	GPS[g] 4 Hz, 40 L 54 H		L: 88 ± 9 H: 92 ± 10			*0-2.0 m·s^{-1}* L: 32.5 ± 4.2 m·min^{-1} H: 33.1 ± 4.0 m·min^{-1}	*2.0-3.5 m·s^{-1}* L: 28.5 ± 6.5 m·min^{-1} H: 29.8 ± 5.8 m·min^{-1}	*3.5-5.0 m·s^{-1}* L: 18.5 ± 6.0 m·min^{-1} H: 18.3 ± 4.5 m·min^{-1}		*5.0-6.0 m·s^{-1}* L: 5.5 ± 2.0 m·min^{-1} H: 6.3 ± 2.6 m·min^{-1}	*≥6.0 m·s^{-1}* L: 2.9 ± 3.6 m·min^{-1} H: 4.2 ± 2.4 m·min^{-1}
Vescovi & Goodale, 2015	Int	GPS[h] 5 Hz, 134 T		T: 95 ± 5 (92-98)		T: 7.4 ± 0.5 (7.1-7.6)	*0-2.2 m·s^{-1}* T: 36 ± 2 m·min^{-1} (35-38)	*2.2-4.4 m·s^{-1}* T: 36 ± 5 m·min^{-1} (33-39)		*4.4-5.5 m·s^{-1}* T: 14 ± 3 m·min^{-1} (13-16)		*>5.5 m·s^{-1}* T: 8 ± 4 m·min^{-1} (6-11)

Article	Comp	Device, no. files	Total match distance (m)	Relative match distance (m·min^{-1})	Sprints/ Accel (n)	Max speed (m·s^{-1})	Distance covered per speed zone					
							0 m·s^{-1}	2.2 m·s^{-1}	3.5 m·s^{-1}		5.0 m·s^{-1}	5.5 m·s^{-1}
Clarke et al., 2014	Nat, E	GPS[b] 5 Hz, 24 T		T: 86 ± 7								
Clarke et al., 2017b	Nat	GPS[a] 5 Hz, 90 T		T: 98 ± 12		T: 7.4 ± 0.5						
Portillo et al., 2014	Nat	GPS[b] 15 Hz, 21 T 27 FH 22 SH	T: 1363 ± 222 FH: 719 ± 148 SH: 615 ± 146		*Sprints* T: 1.9 ± 1.4 *Accel* FH: 6.0 ± 2.2 SH: 4.5 ± 2.2	T: 6.0 ± 0.7 FH: 5.8 ± 0.7 SH: 6.2 ± 0.7	*0-1.7 m·s^{-1}* T: 524 ± 137 m FH: 259 ± 63 m SH: 251 ± 78 m	*1.7-3.5 m·s^{-1}* T: 437 ± 97 m FH: 237 ± 67 m SH: 213 ± 52 m	*3.5-3.9 m·s^{-1}* T: 157 ± 51 m FH: 86 ± 34 m SH: 71 ± 25 m	*3.9-5.0 m·s^{-1}* T: 199 ± 79 m FH: 106 ± 45 m SH: 88 ± 46 m	*5.0-5.5 m·s^{-1}* T: 46 ± 33 m FH: 26 ± 24 m SH: 19 ± 15 m	*>5.5 m·s^{-1}* T: 47 ± 39 m FH: 15 ± 21 m SH: 27 ± 28 m
Vescovi & Goodale, 2015	Nat	GPS[h] 5 Hz, 78 T		T: 91 ± 11 (84-97)		T: 6.8 ± 0.8 (6.4-7.3)	*0-2.2 m·s^{-1}* T: 39 ± 6 m·min^{-1} (36-42)	*2.2-4.4 m·s^{-1}* T: 38 ± 12 m·min^{-1} (31-45)		*4.4-5.5 m·s^{-1}* T: 10 ± 4 m·min^{-1} (7-12)		*>5.5 m·s^{-1}* T: 4 ± 3 m·min^{-1} (2-6)

Data are presented as mean, mean ± SD, or range.
Accel = Accelerations, B = Backs, Comp = Competition, E = Elite athletes, ED = Energy drink, F = Forwards, FH = First half, H = High score differential, Int = International tournament, L= Low score differential, Nat = National tournament, P = Placebo, SH = Second half, T = Total, WS = World Series.

[a]SPI HPU, GPSports Systems, Australia.
[b]SPI Pro X, GPSports, Australia.
[c]Minimax S4, Catapult Innovations, Australia.
[d]STATSports Viper, STATSports, UK.
[e]JOHAN trackers, JOHAN Sports, the Netherlands.
[f]SPI Elite, GPSports, Australia.
[g]VX sport 220, Visuallex Sport International, New Zealand.
[h]SPI Pro, GPSports, Australia.

Appendix B4. HR match response of female Rugby Sevens athletes

Article	Comp	Device, no. files	Max HR ($beats \cdot min^{-1}$)	Mean HR ($beats \cdot min^{-1}$)	HR Zones (% time)						
					<60 % HR max	60 % HR max	70 % HR max	80 % HR max	90 % HR max	95 % HR max	100 % HR max
Del Coso et al., 2013	Int	HR monitor[a] 5 Hz, 28 ED 28 P	ED: 189 ± 10 P: 188 ± 9	ED: 168 ± 7 P: 164 ± 6							
Goodale et al., 2017	Int (WS)	HR monitor[a] 1 Hz, 191 T 103 B 88 F		T: 170 ± 8 B: 170 ± 7 F: 169 ± 8	*50-59 %* T: 1.0 ± 1.0 B: 1.0 ± 1.0 F: 1.0 ± 1.0	*60-69 %* T: 2.0 ± 3.0 B: 2.0 ± 3.0 F: 2.0 ± 4.0	*70-79 %* T: 10.0 ± 7.0 B: 11.0 ± 7.0 F: 9.0 ± 8.0	*80-89 %* T: 40.0 ± 16.0 B: 38.0 ± 14.0 F: 39.0 ± 18.0	*≥90 %* T: 49.0 ± 21.0 B: 49.0 ± 18.0 F: 50.0 ± 24.0		
Malone et al., 2020	Int (WS)	HR monitor[b], 250 T 131 B 119 F	T: 187 ± 12 B: 188 (184-190) F: 186 (182-189)	T: 171 ± 9 B: 173 (167-178) F: 170 (165-176)	*≤60 %* B: 1.3 (0.8-2.1) F: 1.2 (0.6-2.0)	*61-70 %* B: 8.3 (4.2-10.5) F: 18.3 (11.3-20.5)	*71-80 %* B: 14.9 (12.3-17.2) F: 21.4 (19.2-23.5)	*81-90 %* B: 50.3 (42.3-52.6) F: 42.1 (42.6-51.3)	*91-95 %* B: 19.1 (15.4-21.3) F: 15.7 (13.4-17.3)	*≥95 %* B: 6.1 (3.1-8.3) F: 2.1 (1.3-3.1)	
Portillo et al., 2014	Int	HR monitor[c], 23 T 36 FH 30 SH	T: 186 ± 9	T: 164 ± 9	*<60%* FH: 0.3 ± 0.8 SH: 0.0 ± 0.0	*61-70 %* FH: 2.3 ± 3.2 SH: 0.9 ± 1.4	*71-80 %* FH: 8.6 ± 7.3 SH: 7.4 ± 6.4	*81-90 %* FH: 29.4 ± 12.7 SH: 31.7 ± 13.0	*91-95 %* FH: 33.8 ± 10.9 SH: 31.6 ± 7.4	*>95 %* FH: 25.0 ± 14.8 SH: 28.3 ± 17.8	
Suarez-Arrones et al., 2012	Int	HR monitor[b], 17 FH 17 SH	FH: 188 ± 12 SH: 190 ± 10	FH: 167 ± 9 SH: 169 ± 10							
Vescovi & Goodale, 2015	Int	HR monitor[c], 134 T	T: 187 ± 6 (184-190)	T: 172 ± 7 (167-178)	*<80 %* T: 13.0			*80-90 %* T: 32.0	*>90 %* T: 55.0		

Article	Comp	Device, no. files	Max HR (beats·min^{-1})	Mean HR (beats·min^{-1})	HR Zones (% time)						
					<60% HR max	60% HR max	70% HR max	80% HR max	90% HR max	95% HR max	100% HR max
Portillo et al., 2014	Nat	HR monitor[c], 26 T 27 FH 22 SH	T: 178 ± 12	T: 155 ± 14	*<60 %* FH: 0.2 ± 0.9 SH: 0.5 ± 2.4	*61-70 %* FH: 6.2 ± 7.6 SH: 3.5 ± 7.0	*71-80 %* FH: 18.2 ± 12.6 SH: 17.9 ± 13.5	*81-90 %* FH: 41.6 ± 13.1 SH: 36.9 ± 16.7	*91-95 %* FH: 22.9 ± 11.9 SH: 26.3 ± 16.0	*>95 %* FH: 10.7 ± 9.4 SH: 15.3 ± 11.8	
Vescovi & Goodale, 2015	Nat	HR monitor[c], 78	T: 194 ± 5 (191-198)	T: 180 ± 9 (174-186)	*<80 %* T: 6.0			*80-90 %* T: 28.0	*>90 %* T: 66.0		

Data are presented as mean, mean ± SD, or range.
B = Backs, Comp = Competition, F = Forwards, ED = Energy drink, FH = First half, HR = Heart rate, Int = International tournament, Nat = National tournament, P = Placebo, SH = Second half, T = Total, WS = World Series.

[a]T31, Polar Electro Oy, Finland.
[b]Polar Team Sport System; Polar Electro Oy, Kempele, Finland.
[c]Polar Electro, Kempele, Finland.

Appendix B5. Anthropometric characteristics of female Rugby Sevens athletes

Article	Participants		Height	Body Mass	Body Composition
	n	Level	(m)	(kg)	
Agar-Newman et al., 2017	13	Elite – WS (B)	1.66 ± 0.06	66.4 ± 3.5	7 SF: 84.4 ± 26.1 mm
	11	Elite – WS (F)	1.70 ± 0.04	72.9 ± 4.8	7 SF: 95.0 ± 12.3 mm
Clarke et al., 2014	22	Elite – WS	1.68 ± 0.06	69.0 ± 7.0	7 SF: 85.0 ± 15.0 mm
Clarke et al., 2015c	12	Elite – WS	1.67 ± 0.04	65.8 ± 4.6	
Clarke et al., 2015a	12	Elite – WS	1.68 ± 0.04	68.2 ± 7.7	7 SF: 75.0 ± 10.7 mm
Clarke et al., 2015b	12	Elite – WS	1.67 ± 0.04	65.8 ± 4.6	
Clarke et al., 2017b	11	Elite – WS	1.69 ± 0.02	68.6 ± 4.4	7 SF: 67.0 ± 14.0 mm
Clarke et al., 2017a	23	Elite – WS	1.72 ± 0.05	69.1 ± 6.3	
Clarke et al., 2017c	12	Elite – WS	1.69 ± 0.02	68.6 ± 4.4	
Del Coso et al., 2013	16	Elite	1.66 ± 0.07	66.0 ± 7.0	BF: 16.6 ± 2.8%[a]
Fuller et al., 2017	197	Elite – WS	1.69 ± 0.06	67.4 ± 6.1	
	221	Elite – WS	1.68 ± 0.06	67.8 ± 6.0	
	148	Elite – Oly	1.67 ± 0.06	66.4 ± 6.7	
Gathercole et al., 2015	12	Elite	1.69 ± 0.06	69.5 ± 4.9	
Goodale et al., 2016	12	Elite – WS	1.68 ± 0.07	70.0 ± 4.9	7 SF: 86.8 ± 11.2 mm
	12	(HM)	1.69 ± 0.04	68.7 ± 5.7	7 SF: 91.6 ± 28.4 mm
		Elite – WS (LM)			
Goodale et al., 2017	20	Elite – WS	1.68 ± 0.06	69.0 ± 5.0	
Griffin et al., 2017	24	Elite – WS	1.68 ± 0.05	68.0 ± 6.0	
Griffin et al., 2016	24	Elite – WS	1.68 ± 0.05	68.0 ± 6.0	
Ma et al., 2016	10	Elite (B)	1.69 ± 0.02	64.7 ± 11.2	
	7	Elite (F)	1.63 ± 0.10	68.0 ± 8.1	
Malone et al., 2020	27	Elite – WS	1.68 ± 0.07	67.9 ± 4.3	
Misseldine et al., 2021	7	Elite (B)	1.67 ± 0.05	62.4 ± 4.4	
	5	Elite (F)	1.70 ± 0.03	69.8 ± 2.0	
Ohya et al., 2015	12	Elite (B)	1.64 ± 0.05	60.6 ± 3.6	BF: 15.4 ± 3. %[b]
	11	Elite (F)	1.66 ± 0.03	68.2 ± 8.4	BF: 18.1 ± 3.5%[b]
Portillo et al., 2014	10	Elite	1.67 ± 0.07	65.4 ± 5.0	BF: 19.3 ± 4.1%[c]
Portillo et al., 2017	16	Elite	1.66 ± 0.07	66.0 ± 7.0	BF: 16.6 ± 2.8%[a]
Reyneke et al., 2018	15	Elite – WS	1.68 ± 0.07	67.5 ± 6.3	
Suarez-Arrones et al., 2012	12	Elite	1.65 ± 0.06	63.7 ± 4.8	
Valenzuela et al., 2018	7	Elite – Oly (HP)	1.67 ± 0.05	66.7 ± 3.7	BMI: 24.0 ± 0.8 $kg \cdot m^{-2}$
	7	Elite – Oly (LP)	1.71 ± 0.05	69.1 ± 5.1	BMI: 23.5 ± 0.9 $kg \cdot m^{-2}$
Clarke et al., 2015c	10	Nonelite	1.67 ± 0.03	66.1 ± 7.9	
Clarke et al., 2015b	10	Nonelite	1.67 ± 0.03	66.1 ± 7.9	
Clarke et al., 2017b	22	Nonelite	1.70 ± 0.07	70.4 ± 9.3	7 SF: 89.0 ± 20.0 mm
Leite et al., 2016	7	Nonelite	1.63 ± 0.07	67.1 ± 11.4	3 SF: 172.0 ± 56.0 mm
Mirsafaei Rizi et al., 2017	14	Nonelite	1.61 ± 0.04	53.3 ± 5.1	
Ma et al., 2016	44	Nonelite (B)	1.65 ± 0.06	66.0 ± 9.5	
	33	Nonelite (F)	1.65 ± 0.06	71.7 ± 13.9	
Portillo et al., 2014	10	Nonelite	1.67 ± 0.03	66.5 ± 5.4	BF: 21.5 ± 5.1%[c]

Data are presented as mean ± SD.
3 SF = Sum of 3 skinfolds, 7 SF = Sum of 7 skinfolds, B = Backs, BF = Body fat, BMI = Body Mass Index, F = Forwards, HM = High playing minutes, HP = High-power, LM = Low playing minutes, LP = Low-power, Oly = Olympic Games, WS = World Series.

[a]Calculated using 6 skinfolds.
[b]Measured with air displacement plethysmography.
[c]Not specified.

Appendix B6. Acceleration and speed qualities of female Rugby Sevens athletes

Article	Participants		Time (s)				Maximal Speed ($m \cdot s^{-1}$)
	n	level	0-10 m	0-30 m	0-40 m	0-50 m	Up to 50 m
Agar-Newman et al., 2017	12	Elite – WS (B)	1.81 ± 0.03[a,d]		5.60 ± 0.14[a,d]		8.21 ± 0.26[a,d]
	11	Elite – WS (F)	1.84 ± 0.04[a,d]		5.72 ± 0.12[a,d]		8.02 ± 0.25[a,d]
Clarke et al., 2017b	11	Elite – WS	1.76 ± 0.05[b]		5.50 ± 0.16[b]		8.23 ± 0.34[b]
Goodale et al., 2016	12	Elite – WS (HM)	1.83 ± 0.05[a,d]	4.41 ± 0.13[a,d]	5.66 ± 0.16[a,d]		8.13 ± 0.26[a,d]
	12	Elite – WS (LM)	1.82 ± 0.03[a,d]	4.39 ± 0.07[a,d]	5.66 ± 0.11[a,d]		8.06 ± 0.26[a,d]
Misseldine et al., 2021	7	Elite (B)					7.80 ± 0.30[c,d]
	5	Elite (F)					7.50 ± 0.40[c,d]
Ohya et al., 2015	9	Elite (B)		4.64 ± 0.19[a]		7.26 ± 0.29[a]	
	9	Elite (F)		4.74 ± 0.11[a]		7.39 ± 0.16[a]	
Vescovi & Goodale, 2015	16	Elite					7.58 ± 0.19[a,e]
Clarke et al., 2017b	22	Nonelite	1.82 ± 0.06[b]		5.79 ± 0.17[b]		7.77 ± 0.26[b]
Vescovi & Goodale, 2015	13	Nonelite					7.22 ± 0.42[a,e]

Data are presented as mean ± SD.
B = Backs, F = Forwards, HM = High playing minutes, LM = Low playing minutes, WS = World Series.

[a]Measured with timing lights (Brower Timing System, Utah, USA).
[b]Measured with timing lights (Fusion Sport, Brisbane, Australia).
[c]Measured with GPS units (JOHAN Sports, Noordwijk, the Netherlands).
[d]Performed on artificial turf.
[e]Performed indoor.

Appendix B7. Power characteristics of female Rugby Sevens athletes

Article	Participants		VJ	CMJ				SLJ	STJ	Other
	n	level	Height (cm)	Height (cm)	RPP ($W\cdot kg^{-1}$)	RMP ($W\cdot kg^{-1}$)	PV ($m\cdot s^{-1}$)	Distance (cm)	Distance (cm)	
Agar-Newman et al.,	12	Elite – WS (B)						229 ± 11	705 ± 32	
2017	11	Elite – WS (F)						228 ± 9	691 ± 28	
Clarke et al., 2017b	11	Elite – WS	49.6 ± 3.8[a]							
Clarke et al., 2015c	12	Elite			64 ± 9[b]	39 ± 4[b]	3.2 ± 0.2[b]			
Del Coso et al., 2013	16	Elite (ED)								15-s RJ, TP: 25.6 ± 11.8 kW[c]
	16	Elite (P)								15-s RJ, TP: 23.5 ± 10.1 kW[c]
Gathercole et al., 2015	12	Elite			57 ± 5[d]					
Goodale et al., 2016	12	Elite – WS (HM)						227 ± 9	692 ± 25	
	12	Elite – WS (LM)						230 ± 11	705 ± 35	
Ohya et al., 2015	10	Elite – B		38.4 ± 4.2[e]						SJ, Height: 33.0 ± 3.5 cm[e]
	10	Elite – F		37.5 ± 4.0[e]						SJ, Height: 32.9 ± 3.6 cm[e]
Valenzuela et al., 2018	7	Elite – Oly (HP)								WAnT, RPP: 9.80 ± 0.25 $W\cdot kg^{-1}$[f]
	7	Elite – Oly (LP)								WAnT, RPP: 8.94 ± 0.45 $W\cdot kg^{-1}$[f]
Clarke et al., 2017b	22	Nonelite	47.4 ± 5.5[a]							
Clarke et al., 2015c	10	Nonelite			56 ± 10[b]	33 ± 7[b]	3.0 ± 0.3[b]			
Leite et al., 2016	7	Nonelite								Bench Press (Concentric) MP: 195.0 ± 48.7 W[g], 30% 1RM, PP: 201.6 ± 70.8 W[g], 40% 1RM, PP: 204.7 ± 49.0 W[g], 50% 1RM, PP: 200.3 ± 40.6 W[g], 60% 1RM, PP: 173.4 ± 40.2 W[g]

Data are presented as mean ± SD.
15-s RJ = 15 seconds rebound jump, B = Backs, CMJ = Countermovement jump, ED = Energy drink, F = Forwards, HM = High playing minutes, HP = High-power, LM = Low playing minutes, LP = Low-power, MP = Mean power, Oly = Olympic Games, P = Placebo, PV = Peak velocity, RM = Repetition Maximum, RMP = Relative mean power, RPP = Relative peak power, PP = Peak power, SJ = Squat jump, SLJ = Standing long jump, STJ = Standing triple jump, TP = Total power, VJ = Vertical jump, WAnT = Wingate Anaerobic test, WS = World Series.

[a]Measured with Vertec (Swift Performance Equipment, Queensland, Australia).
[b]Measured with linear position transducer (GymAware, Kinetic Performance, Australia).
[c]Measured with force plate (Quattrojump, Kistler, Switzerland).
[d]Measured with force plate (400 series, Fitness Technology, Australia) and position transducer (Celesco, Chatsworth, USA).
[e]Measured with a switch mat system (Multi jump tester, DKH CO., Tokyo, Japan).
[f]Measured with magnetically braked stationary cycle ergometer (SNT Medical, Cardgirus, Spain. [g]Measured with triaxial accelerometer (Myotest S4P, Sion, Switzerland).

Appendix B8. Strength qualities of female Rugby Sevens athletes

Article	Participants level	Front Squat 1 RM (kg)	Front Squat Rel 1 RM ($kg \cdot kg^{-1}$)	Power Clean 1 RM (kg)	Power Clean Rel 1 RM ($kg \cdot kg^{-1}$)	Bench Press 1 RM (kg)	Bench Press Rel 1 RM ($kg \cdot kg^{-1}$)	Neutral Grip Pull-Up 1 RM (kg)	Neutral Grip Pull-Up Rel 1 RM ($kg \cdot kg^{-1}$)
Agar-Newman et al., 2017	Elite – WS (B) (*n*)	82.5 ± 11.3 (8)	1.2 ± 0.2 (8)	68.2 ± 6.2 (8)	1.0 ± 0.1 (8)	61.8 ± 7.1 (11)	0.9 ± 0.1 (11)	78.1 ± 6.7 (12)	1.2 ± 0.1 (12)
	Elite – WS (F) (*n*)	84.5 ± 5.8 (9)	1.1 ± 0.1 (9)	73.5 ± 4.5 (7)	1.0 ± 0.0 (7)	68.8 ± 7.1 (10)	0.9 ± 0.1 (10)	86.3 ± 5.2 (9)	1.2 ± 0.1 (9)
Goodale et al., 2016	Elite – WS (HM) (*n*)	84.2 ± 7.9 (8)	1.2 ± 0.2 (8)	71.8 ± 4.8 (7)	1.0 ± 0.1 (7)	68.4 ± 6.3 (11)	1.0 ± 0.1 (11)	84.0 ± 8.2 (10)	1.2 ± 0.1 (10)
	Elite – WS (LM) (*n*)	83.0 ± 9.6 (8)	1.2 ± 0.2 (8)	69.4 ± 7.2 (7)	1.0 ± 0.1 (7)	62.2 ± 8.1 (11)	0.9 ± 0.1 (11)	79.1 ± 5.4 (10)	1.2 ± 0.1 (10)
Leite et al., 2016	Nonelite (*n*)					40.3 ± 7.3[a] (7)			

Data are presented as mean ± SD.

B = Backs, F = Forwards, HM = High playing minutes, LM = Low playing minutes, Rel = Relative, RM = Repetition Maximum, WS = World Series.

[a]Performed on a guided bar bench.

Appendix B9. Aerobic capacities of female Rugby Sevens athletes

Article	Participants		Yo-Yo IR1	VO_2 max	Other
	n	level			
Agar-Newman et al., 2017	13	Elite – WS (B)			1600 m, time: 390 ± 28 s[a]
	10	Elite – WS (F)			1600 m, time: 377 ± 25 s[a]
Clarke et al., 2014	22	Elite – WS	TD: 1200 ± 320 m[b] Lev: 16.3 ± 1.0[b]	VO_2 max: 46.5 ± 5.2 $ml \cdot kg^{-1} \cdot min^{-1}$[c] vVO_2 max: 3.7 ± 0.3 $m \cdot s^{-1}$[c]	Critical v: 3.2 ± 0.3 $m \cdot s^{-1}$[d]
Clarke et al., 2017b	11	Elite – WS	TD: 1702 ± 329 m		
Clarke et al., 2015a	7	Elite – WS		VO_2 max: 51.0 ± 4.0 $ml \cdot kg^{-1} \cdot min^{-1}$[c] vVO_2 max: 4.1 ± 0.6 $m \cdot s^{-1}$[c] vVT_2: 3.5 ± 0.3 $m \cdot s^{-1}$[c]	
Goodale et al., 2016	12	Elite – WS (HM)			1600 m, time: 374 ± 20 s[e]
	12	Elite – WS (LM)			1600 m, time: 393 ± 30 s[e]
Suarez-Arrones et al., 2012	12	Elite		VO_2 max: 51.1 ± 3.6 $ml \cdot kg^{-1} \cdot min^{-1}$[f]	
Vescovi & Goodale, 2015	16	Elite	TD: 1160 ± 191 m[g]		
Clarke et al., 2017b	22	Nonelite	TD: 1058 ± 249 m		
Vescovi & Goodale, 2015	13	Nonelite	TD: 781 ± 129 m[g]		

Data are presented as mean ± SD.
B = Backs, F = Forwards, HM = High playing minutes, Lev = Last level completed, LM = Low playing minutes, TD = Total distance, v = Velocity, VO_2 max = Maximal oxygen uptake, VT_2 = Second ventilatory threshold, WS = World Series, Yo-Yo IR1 = Yo-Yo Intermittent Recovery Test Level 1.

[a]Performed on a 400-m gravel track.
[b]Performed indoor.
[c]Performed on a custom-built motorised treadmill (Australian Institute of Sport).
[d]Performed on grass.
[e]Performed on a 400-m running track.
[f]Performed on a treadmill and measured with Oxycon Delta de Jaeger, Hoechberg, Germany.
[g]Performed indoor.

Appendix C. Appendices for Chapter 3

Appendix C1. Correlations between physical tests mean values. The variables have been ordered and outlined to show clusters with generally higher correlations between variables within the clusters than between the clusters.

Variable	1	2	3	4	5	6	7	8
1. 10-m average speed		.70	.64	.51	.31	-.32	-.23	.05
2. 30-m average speed	.70		.99	.91	.59	-.27	-.37	.03
3. 40-m average speed	.64	.99		.96	.62	-.25	-.42	-.04
4. Maximal speed	.51	.91	.96		.62	-.19	-.46	-.13
5. Bronco average speed	.31	.59	.62	.62		.18	.09	.23
6. Bench press 1RM	-.32	-.27	-.25	-.19	.18		.76	.29
7. Back squat 1RM	-.23	-.37	-.42	-.46	.09	.76		.47
8. CMJ height	.05	.03	-.04	-.13	.23	.29	.47	

Uncertainty (90% compatibility limits): ~±0.31 to ~±0.03 for correlations of 0.00 to 0.95 respectively assuming a sample size of ~30.

Appendix C2. Correlations between match running mean values. The variables have been ordered and outlined to show clusters with generally higher correlations between variables within the clusters than between the clusters.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Match maximal speed		.56	.61	.49	.40	.40	.06	-.25	.03	-.09	-.11	.03	-.07	.03
2. Distance >7.5 $m \cdot s^{-1}$	.56		.53	.42	.32	.22	.08	-.19	.02	.05	-.03	.03	-.03	.00
3. Distance >5.5 $m \cdot s^{-1}$	.61	.53		.94	.84	.88	.38	-.16	.17	-.01	.00	.24	.03	.30
4. Distance >5.0 $m \cdot s^{-1}$	.49	.42	.94		.96	.98	.56	.01	.29	.15	.13	.37	.11	.45
5. Distance >4.7 $m \cdot s^{-1}$	.40	.32	.84	.96		.96	.72	.23	.42	.28	.26	.52	.14	.52
6. Distance 5.0-7.5 $m \cdot s^{-1}$	.40	.22	.88	.98	.96		.58	.05	.30	.15	.15	.39	.13	.48
7. Distance >3.5 $m \cdot s^{-1}$	.06	.08	.38	.56	.72	.58		.83	.76	.64	.60	.73	.16	.46
8. Distance 3.5-5.0 $m \cdot s^{-1}$	-.25	-.19	-.16	.01	.23	.05	.83		.72	.67	.63	.63	.12	.26
9. Total distance	.03	.02	.17	.29	.42	.30	.76	.72		.71	.70	.56	.23	.30
10. Sprints	-.09	.05	-.01	.15	.28	.15	.64	.67	.71		.85	.61	.41	.43
11. Accelerations	-.11	-.03	.00	.13	.26	.15	.60	.63	.70	.85		.56	.55	.46
12. Decelerations	.03	.03	.24	.37	.52	.39	.73	.63	.56	.61	.56		.14	.62
13. High-intensity accelerations	-.07	-.03	.03	.11	.14	.13	.16	.12	.23	.41	.55	.14		.69
14. High-intensity decelerations	.03	.00	.30	.45	.52	.48	.46	.26	.30	.43	.46	.62	.69	

Uncertainty (90% compatibility limits): ~±0.31 to ~±0.03 for correlations of 0.00 to 0.95 respectively assuming a sample size of ~30.

Appendix C3. Correlations between match actions mean values. The variables have been ordered and outlined to show clusters with generally higher correlations between variables within the clusters than between the clusters.

Variable	1	2	3	4	5	6	7	8	9	10
1. Tries		.53	.33	-.05	.14	-.15	.00	-.10	-.17	.05
2. Line breaks	.53		.49	.08	.31	-.08	-.05	-.15	-.20	.13
3. Work rate	.33	.49		.54	.59	.12	.06	.41	-.15	.35
4. Carries	-.05	.08	.54		.47	-.06	-.07	-.12	-.08	.03
5. Tackle breaks	.14	.31	.59	.47		-.05	.01	-.17	-.07	.09
6. Effective attacking rucks	-.15	-.08	.12	-.06	-.05		.06	.06	.07	.00
7. Handling errors	.00	-.05	.06	-.07	.01	.06		.20	.23	-.09
8. Tackles	-.10	-.15	.41	-.12	-.17	.06	.20		.06	.06
9. Missed tackles	-.17	-.20	-.15	-.08	-.07	.07	.23	.06		-.19
10. Turnovers won	.05	.13	.35	.03	.09	.00	-.09	.06	-.19	

Uncertainty (90% compatibility limits): ~±0.31 to ~±0.03 for correlations of 0.00 to 0.95 respectively assuming a sample size of ~30.

Appendix C4. Correlations between match running and match actions mean values. The variables have been ordered and outlined to show clusters with generally higher correlations between variables within the clusters than between the clusters.

Variable	Tries	Line breaks	Work rate	Carries	Tackle breaks	Effective attacking rucks	Handling errors	Tackles	Missed tackles	Turnovers won
Match maximal speed	.38	.31	.04	-.10	-.01	-.17	-.08	-.05	.00	-.14
Distance >7.5 $m \cdot s^{-1}$	.31	.17	.13	.09	-.03	-.03	-.02	.05	-.02	-.17
Distance >5.5 $m \cdot s^{-1}$	.32	.24	.15	-.06	-.02	-.06	-.13	.11	-.10	-.07
Distance >5.0 $m \cdot s^{-1}$	.26	.22	.17	-.06	-.04	-.05	-.08	.16	-.09	.03
Distance >4.7 $m \cdot s^{-1}$	.18	.16	.16	-.07	-.06	-.03	-.06	.20	-.07	.06
Distance 5.0-7.5 $m \cdot s^{-1}$	.21	.19	.16	-.08	-.03	-.05	-.08	.16	-.09	.07
Distance >3.5 $m \cdot s^{-1}$	-.08	-.05	.05	-.15	-.13	-.01	-.05	.29	.01	.16
Distance 3.5-5.0 $m \cdot s^{-1}$	-.27	-.21	-.05	-.15	-.13	.03	.00	.24	.08	.18
Total distance	-.10	-.11	.11	-.02	-.04	-.03	.02	.28	-.03	.12
Sprints	-.15	-.07	.21	.08	-.05	.07	.06	.39	.02	.06
Accelerations	-.18	-.06	.22	.08	-.02	.03	.00	.37	.02	.16
Decelerations	-.13	-.04	.01	-.17	-.18	.11	-.04	.26	-.03	.12
High-intensity accelerations	.00	.01	.23	.15	.03	.16	.01	.15	.00	.18
High-intensity decelerations	.01	.05	.20	.04	-.06	.12	.01	.21	-.08	.20

Uncertainty (90% compatibility limits): ~±0.31 to ~±0.03 for correlations of 0.00 to 0.95 respectively assuming a sample size of ~30.

Appendix D. Ethical approval

The University of Waikato
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Julie Barbour
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THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

3 September 2019

Francesco Stefano Sella
By email: fss4@students.waikato.ac.nz

Dear Francesco

UoW HREC(Health)#2018-10: Maximising Physical Performance in Female Rugby Sevens Athletes – Updated Approval

Thank you for submitting your amendment request for your project, previously approved as HREC(Health)#2018-10.

We are now pleased to provide approval for the addition of participants in teams outside of the previously approved Bay of Plenty Women's Rugby Sevens team. Please note that you need to secure permission from appropriate leadership of each team prior to recruitment. This permission must be submitted to the HREC for our records. It may take the form of a letter, email, or a verbal agreement which is reported by you in writing (including name of the individual, date and location of the conversation) to the HREC. We are also happy to approve the additional Strength Assessment Tool.

Please contact the committee by email (humanethics@waikato.ac.nz) if you wish to make changes to your project as it unfolds, quoting your application number with your future correspondence. Any minor changes or additions to the approved research activities can be handled outside the monthly application cycle.

We wish you all the best with your research.

Regards,

Julie Barbour (PhD)
Chairperson
University of Waikato Human Research Ethics Committee

The University of Waikato
Private Bag 3105
Gate 1, Knighton Road
Hamilton, New Zealand

Human Research Ethics Committee
Julie Barbour
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THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

10-9-2018

Francesco Stefano Sella
By email: fss4@students.waikato.ac.nz

Dear Francesco

UoW HREC(Health)#2018-10: Methods of assessing, monitoring and improving physical qualities in elite Women's Rugby Sevens players

Thank you for submitting your updated application HREC(Health)#2018-10 for full ethical approval.

We are now pleased to provide formal approval for your project within the parameters outlined within your application.

Please contact the committee by email (humanethics@waikato.ac.nz) if you wish to make changes to your project as it unfolds, quoting your application number with your future correspondence. Any minor changes or additions to the approved research activities can be handled outside the monthly application cycle.

We wish you all the best with your research.

Regards,

Karsten Zegwaard PhD
Acting Chairperson
University of Waikato Human Research Ethics Committee

Appendix E. Co-authorship forms

Appendix E1. Co-authorship form for Chapter 2

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Co-Authorship Form

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Chapter 2
Sella FS, McMaster DT, Beaven CM, Gill ND, Hébert-Losier K. Match demands, anthropometric characteristics, and physical qualities of female Rugby Sevens athletes: A systematic review, The Journal and Strength and Conditioning Research, 33 (12), 3463-3474, 2019.

Nature of contribution by PhD candidate	Development of the research question, literature search, study selection, quality assessment, data extraction and analysis, results interpretation, manuscript preparation, and journal submission.
Extent of contribution by PhD candidate (%)	85%

CO-AUTHORS

Name	Nature of Contribution
Dr. Daniel Travis McMaster	Development of the research question and manuscript revision.
Dr. Christopher Martyn Beaven	Development of the research question, data analysis, and manuscript revision.
Dr. Nicholas David Gill	Development of the research question and manuscript revision.
Dr. Kim Hébert-Losier	Development of the reserch question, quality assessment, data analysis, and manuscript revision.

Certification by Co-Authors

The undersigned hereby certify that:

- the above statement correctly reflects the nature and extent of the PhD candidate's contribution to this work, and the nature of the contribution of each of the co-authors; and

Name	Signature	Date
Dr. Daniel Travis McMaster		28/10/2022
Dr. Christopher Martyn Beaven		28/10/2022
Dr. Nicholas David Gill		28/10/2022
Dr. Kim Hébert-Losier		28/10/2022

Appendix E2. Co-authorship form for Chapter 3

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Chapter 3
Sella FS, Hopkins WG, Beaven CM, McMaster DT, Gill ND, Hébert-Losier K. The associations between physical-test performance and match performance in women's Rugby Sevens players, Biology of Sport, accepted for publication.

Nature of contribution by PhD candidate	Development of the research question, participants recruitment, data collection and analysis, results interpretation, manuscript preparation, and journal submission.
Extent of contribution by PhD candidate (%)	80%

CO-AUTHORS

Name	Nature of Contribution
Prof. William G. Hopkins	Data analysis, results interpretation, manuscript preparation, and manuscript revision.
Dr. Christopher Martyn Beaven	Development of the research question and manuscript revision.
Dr. Daniel Travis McMaster	Development of the research question, participants recruitment, data collection, and manuscript revision.
Dr. Nicholas David Gill	Development of the research question, participants recruitment, and manuscript revision.
Dr. Kim Hébert-Losier	Development of the research question and manuscript revision.

Certification by Co-Authors

The undersigned hereby certify that:

- the above statement correctly reflects the nature and extent of the PhD candidate's contribution to this work, and the nature of the contribution of each of the co-authors; and

Name	Signature	Date
Prof. William G. Hopkins	[signature]	28/10/2022
Dr. Christopher Martyn Beaven	[signature]	28/10/2022
Dr. Daniel Travis McMaster	[signature]	28/10/2022
Dr. Nicholas David Gill	[signature]	28/10/2022
Dr. Kim Hébert-Losier	[signature]	28/10/2022

July 2015

Appendix E3. Co-authorship form for Chapter 4

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Please indicate the chapter/section/pages of this thesis that are extracted from a co-authored work and give the title and publication details or details of submission of the co-authored work.

Chapter 4
Sella FS, Beaven CM, Gill ND, McMaster DT, Hébert-Losier K. Low-volume high-intensity interval training programmes in female Rugby Sevens players: A pilot study.

Nature of contribution by PhD candidate	Development of the research question, participants recruitment, data collection and analysis, results interpretation, manuscript preparation, and journal submission.
Extent of contribution by PhD candidate (%)	90%

CO-AUTHORS

Name	Nature of Contribution
Dr. Christopher Martyn Beaven	Development of the research question, data analysis, and manuscript revision.
Dr. Nicholas David Gill	Development of the research question and manuscript revision.
Dr. Daniel Travis McMaster	Development of the research question and manuscript revision.
Dr. Kim Hébert-Losier	Development of the research question and manuscript revision.

Certification by Co-Authors

The undersigned hereby certify that:

- the above statement correctly reflects the nature and extent of the PhD candidate's contribution to this work, and the nature of the contribution of each of the co-authors; and

Name	Signature	Date
Dr. Christopher Martyn Beaven		28/10/2022
Dr. Nicholas David Gill		28/10/2022
Dr. Daniel Travis McMaster		28/10/2022
Dr. Kim Hébert-Losier		28/10/2022

July 2015

Appendix E4. Co-authorship form for Chapter 5

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Chapter 5
Sella FS, Beaven CM, Sims ST, McMaster DT, Gill ND, Hébert-Losier K. The effects of menstrual cycle phase on physical performance in female Rugby athletes: A case-study. The Journal of Sport and Exercise Science, 5 (5), 310-320, 2021.

Nature of contribution by PhD candidate	Development of the research question, participants recruitment, data collection and analysis, results interpretation,manuscript preparation, and journal submission.
Extent of contribution by PhD candidate (%)	85%

CO-AUTHORS

Name	Nature of Contribution
Dr. Christopher Martyn Beaven	Development of the research question, data collection and analysis, and manuscript revision.
Dr. Stacy T. Sims	Development of the research question, manuscript preparation, and manuscript revision.
Dr. Daniel Travis McMaster	Development of the research question and manuscript revision.
Dr. Nicholas David Gill	Development of the research question and manuscript revision.
Dr. Kim Hébert-Losier	Development of the research question and manuscript revision.

Certification by Co-Authors

The undersigned hereby certify that:

- the above statement correctly reflects the nature and extent of the PhD candidate's contribution to this work, and the nature of the contribution of each of the co-authors; and

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Dr. Christopher Martyn Beaven		28/10/2022
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Appendix E5. Co-authorship form for Appendix A

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Appendix A
Sella FS, Hébert-Losier K, Beaven CM, McMaster DT, Harvey M, Gill ND. Performance in the 1.2 km shuttle run test reflects fitness capacities in Rugby players. The Journal of Australian Strength and Conditioning, 29 (5), 7-14, 2021.

Nature of contribution by PhD candidate	Development of the research question, participants recruitment, data analysis, results interpretation, manuscript preparation, and journal submission.
Extent of contribution by PhD candidate (%)	85%

CO-AUTHORS

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Dr. Kim Hébert-Losier	Development of the research question, manuscript preparation, and manuscript revision.
Dr. Christopher Martyn Beaven	Development of the research question and manuscript revision.
Dr. Daniel Travis McMaster	Development of the research question and manuscript revision.
Mark Harvey	Development of the research question, data collection, and manuscript revision.
Dr. Nicholas David Gill	Development of the research question, data collection, and manuscript revision.

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