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Bowling biomechanics, physical profiles, and injuries among female cricket players

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in fulfilment of the requirements for the degree of
Doctor of Philosophy

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DECLARATION

I, Jolandi Jacobs, acknowledge that the work presented in this research manuscript is solely my own, except where indicated in the preface as a proportion of contribution to peer-reviewed publications. Where information has been derived from other sources, I confirm that this has been identified and referenced within the thesis.

This thesis is submitted for the degree of Doctor of Philosophy in Physiotherapy at the University of the Witwatersrand, Johannesburg, South Africa.

This thesis has not been submitted elsewhere for any degree or examination.

Signed: **Date:** Tuesday, 22 October 2024

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I thank my family and friends for your encouragement while pursuing my goals. If it were not for all of you, I would not be where I am today.

All honour to God.

To girls with big dreams, go and make them happen!

ABSTRACT

The recent surge in interest, participation, and investment in women's cricket has ushered in a more professional environment with heightened competition and popularity. The growth of women's sports and professionalism in female cricket players necessitates support from applied sports science and sports medicine (SSSM) clinicians to enhance well-being and performance. However, higher participation rates and athlete professionalism pose challenges for practitioners due to the lack of injury prevention and performance-enhancement research for female cricket players. This thesis presents four novel papers that aim to address the current gap in research for female cricket players.

The first paper, a scoping review, consolidates evidence from 158 studies in SSSM for female cricket players, identifying research gaps and highlighting future topics. The second paper investigates the physical profiles and preparation strategies of female cricket players, revealing differences in body composition, muscle strength, power and fitness among player roles. The third paper explores injury profiles of female cricket players, reporting an incidence of 85.23 injuries per 1000 player match days, with pace bowlers experiencing the highest incidence compared to other player roles. Fielding was the most injury-prone activity, emphasising the need for injury prevention strategies, particularly in training. Most injuries are due to direct contact and are acute. The fourth paper compares anthropometric and biomechanical factors of elite male and female pace bowlers. The results indicate sex-specific differences, such as increased rotational movements observed in female pace bowlers during the delivery

stride and variations in the sequence of the trunk side flexion strategy, emphasising the need for tailored coaching and preparation strategies specific to female bowlers.

The findings from this thesis provide ample SSSM evidence to guide the management of female cricket player's well-being in a professional environment. This thesis not only offers applied guidelines for clinicians but also highlights priority areas for future research.

SUMMARY

Recent interest, participation, and investment in women's cricket have catalysed a more professional environment, heightened competition, and popularity. The growth of women's sports and the professionalism of females playing cricket as a full-time profession have fostered a need for support for these players. Applied sports science and sports medicine (SSSM) clinicians play a vital role in implementing evidence-based methods to enhance the well-being and performance of female players. The increased participation and professionalism of women's cricket and the lack of available research present a challenge for applied clinicians. Research on SSSM for female cricket players is needed to guide clinical practice and support the well-being and performance of female cricket players. The thesis addresses the current gap in research. It presents four novel papers to guide clinical practice: i) a scoping review on applied sports science and medicine for female cricket players, ii) an investigation into physical profiles and preparation of female cricket players, iii) an exploration of injury incidence in women's cricket, and iv) a comparative study between male and female bowling biomechanics.

The first paper, a scoping review (Chapter 3), pools the available evidence for SSSM for female cricket players. The scoping review presents 158 studies and covers eight SSSM themes: injury, performance, psychology, health, physical characteristics, match characteristics, fatigue and recovery, and nutrition and hydration. The review identifies research gaps for women's cricket and prioritises these topics for future

research: female health, i.e. menstrual cycle, energy deficiency, breast health, and injury prevention strategies.

The second paper (Chapter 4) investigates the physical profiles and preparation of all-rounders, batters, and bowlers in sub-elite women's cricket. Findings from this study will provide SSSM practitioners with baseline values to compare current clinical findings and inform physical preparation strategies. This study reveals differences in body composition, muscle strength, overall peak power and aerobic fitness among different player roles in women's cricket. This study identified asymmetries in different player groups and highlighted differences in all-rounders, batters and bowlers.

The third paper (Chapter 5) explores injury profiles in sub-elite female cricket players. The study reported an injury incidence of 85.23 per 1000 player match days, with pace bowlers experiencing the highest incidence compared to other player roles. Fielding was the primary cause of injuries, emphasising the importance of injury prevention strategies for bowlers and fielders, particularly in training compared to matches. Most injuries were direct contact and acute in nature.

The fourth paper (Chapter 6) compares anthropometric and biomechanical factors in elite male and female pace bowlers. Females present with a more front on approach when arriving at the delivery stride, implement greater rotational displacement during the delivery stride and a different trunk side flexion strategy compared to males. This study describes the sex-specific differences in bowlers and encourages female-specific biomechanical coaching strategies.

This research provides evidence-based SSSM findings to support players and effectively enhance the professional development of women's cricket. The thesis also provides applied guidelines for clinicians and highlights priority areas for future research. The potential impact of this research extends to applied SSSM practitioners and stakeholders in women's cricket, advocating for evidence-based practices to support the well-being and performance of female cricket players.

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LIST OF ABBREVIATIONS

Abbreviation	Definition
1RM	one repetition maximum
AMS	Athlete Management System
ANOVA	analysis of variance
BBFC	before back foot contact
BF%	body fat percentage
BFC	back foot contact
BMD	bone mineral density
BMI	body mass index
BR	ball release
CMJ	countermovement jump
CSA	Cricket South Africa
CT	computed tomography
D	dominant
ECB	England Cricket Board
FFC	front foot contact
h	hours
HT	hop test
ICC	International Cricket Council
ICD	International Classification of Diseases
IMU	inertial measurement unit
IMTP	isometric mid-thigh pull
IOC	International Olympic Committee
IR	internal rotation
IWCC	International Women’s Cricket Council
km	kilometre
km/h	kilometre per hour

kN	kilonewton
LBP	lumbar back pain
LBSI	lumbar bone stress injury
MM%	muscle mass percentage
MRI	magnetic resonance imaging
ms	milliseconds
ND	non-dominant
OA	osteoarthritis
OD	one-day
ODI	One Day International
OSABR	one step after ball release
OSCICS	Orchard Sports Injury Classification System
PU	push-up
RMR	resting metabolic rate
ROM	range of motion
RPE	rate of perceived exertion
RPR	resting pulse rate
s	seconds
SCAT	Sport Concussion Assessment Tool
SD	standard deviation
SLJ	single leg jump
SpO_2	peripheral oxygen saturation
sRPE	session rating of perceived exertion
T20	Twenty-Twenty
TT	time trial
UK	United Kingdom
USA	United States of America
VO_2 max	maximal oxygen uptake
YYIRTL1	Yo-Yo Intermittent Recovery Test Level 1

GLOSSARY OF TERMS

All-rounder: A player who demonstrates ability in both batting and bowling skills. The player's versatility improves the team's performance by balancing their competence in batting and bowling skills (Cashman, 1996).

Anthropometry: Scientific practice of gathering and analysing measurements of human individuals, focusing on physical attributes such as body mass, size, and shape (Tur and Bibiloni, 2019).

Back foot contact: The first impact during the delivery stride of a bowler's technique is back foot contact (Ranson et al., 2008).

Ball release: The sequence of the bowling technique involves back foot contact, followed by front foot impact, and then ball release (Ranson et al., 2008).

Batter: The player who faces the ball delivered from the bowler (Eastaway, 2016).

Biomechanics: The study of the structure, function, and motion of the mechanical aspects of biological systems using the principles of mechanics (Hall, 2022).

Bowler: Bowlers are classified as pace (or fast) and spin (or slow) bowlers. Pace bowlers are either 'fast', 'fast-medium', or 'medium'. Additionally, spin bowlers specialise in off/finger or leg/wrist spin (Orchard et al., 2016).

Countermovement jump: A physical test required by performing a sequence of movements, keeping the chest up and looking forward, bending down, jumping up, landing softly, and assuming the starting position again (Markovic et al., 2004).

Delivery phase: The phase between the back foot contact and front foot contact (Ranson et al., 2008).

Epidemiology: The study of health-related events in specific populations, including their distribution and determinants. Epidemiology knowledge is needed to address health problems effectively (Rothman, 2012).

Fast bowler: A bowler who bowls at high speed and causes the wicketkeeper to position themselves further away from the stumps (Dennis et al., 2003).

Front foot contact: The impact followed by back foot contact and before ball release in the bowling action (Ranson et al., 2008).

Hop test: A physical test required by performing a sequence of movements, including bending down, jumping up, landing with stiff legs on the toes, and promptly jumping off the toes (Sawle et al., 2017).

Illness: An illness is an acquired physical complaint unrelated to injury and has received medical attention, regardless of its effect on absence from matches or training (Mountjoy et al., 2010).

Incidence: The total number of new injuries, including initial and recurrent ones, during a specified time frame. Incidence is reported as athlete exposure hours (Orchard et al., 2016).

Innings: The time a team or player has to bat in a match before being out or finishing their batting turn (Eastaway, 2016).

One step after ball release: The step after ball release or the delivery phase during the bowling action (Olivier et al., 2023a).

One-day match: A match played on one day with limited overs per team (Orchard et al., 2005).

Pace-bowler: The terms "fast" and "fast-medium" bowlers are often combined and referred to as “pace bowlers”. Pace bowlers deliver the ball at a high speed generated from a longer run-up. In contrast, “spin” or “slow bowlers” deliver balls at slower speeds and use a shorter run-up (Felton et al., 2019). All pace or fast bowlers in this thesis were collectively referred to as “pace bowlers”.

Prevalence: The percentage of players or squad members ill and/or injured and unable to be selected for a match at a given moment, divided by the total number of players or squad members available (Orchard et al., 2016).

Proportions: The number of players presenting with an injury divided by the total number of athletes (Knowles et al., 2006).

Psychology: Psychology is the scientific investigation of mental processes and behaviours. The field covers various subjects such as perception, cognition, emotion, personality, and social interaction (American Psychological Association, 2023).

Rate: The number of injuries divided by the number of athlete-exposure times, using an epidemiologic denominator (Knowles et al., 2006).

Non-time-loss injury: When a player is not entirely fit but still able to compete in a match or field, bat, bowl, or keep the wicket as required by the captain of the team or the regulations of the match (Orchard et al., 2016).

Single leg jump: A physical test required by performing a sequence of movements, including maintaining an upright chest, followed by bending down, jumping up, and landing with a gentle impact (Meylan et al., 2009).

Spin bowler: A bowler who bowls at a slower speed and typically causes the wicketkeeper to stand closer to the stumps (Dennis et al., 2003). All slow or spin bowlers in this thesis were collectively referred to as “spin bowlers”.

Time-loss injury: When a player is not entirely fit to compete in a match or cannot field, bat, bowl, or keep the wicket as required by the captain of the team or the regulations of the match (Orchard et al., 2016).

Training volume: The total workload completed during a designated exercise or training within a specified timeframe and often quantified by the number of sets, repetitions, and weights lifted in resistance training or by the overall duration and intensity of cardiovascular exercises (Kraemer and Ratamess, 2004).

Wicketkeeper: The person who is positioned behind the wickets. For spin bowlers, the wicketkeeper is positioned near the wickets; for pace bowlers, they are positioned further away (Orchard et al., 2016).

CHAPTER 1. INTRODUCTION

1.1 Preface

The evolution of women's cricket has been extraordinary, spanning centuries from its inception in the 1700s to its present-day recognition as a widely recognised and highly competitive sport (Guttman, 1991; Odendaal, 2011). Over the years, women's cricket has transformed into a popular sport, with a notable increase in participation, popularity and investments in women's cricket, with players having more opportunities to participate in cricket at school, junior, club, state, and national levels (Jolly, 2021). The journey signifies its transition from a recreational activity to a full-time profession and one that merits its inclusion in the Olympic Games.

The transition from amateur to professional level of play means female athletes will be exposed to higher training loads and intensity (Kelly et al., 2019). This intensity has transformed the game from a recreational activity to a competitive domain as demanding as men’s cricket (Webster et al., 2022). The physicality of women's cricket requires that players train to improve their physical profile to meet the demands of the game (Garcia-Byrne et al., 2020). The combination of a high training workload and frequent match schedule means that frequent injuries may lead to prolonged recovery and rehabilitation time.

The role of sports science and medical professionals working with players to optimise their physical fitness while mitigating the risk of injury has become paramount. The

successful development of women's cricket from grassroots to elite levels relies on a robust support system that can effectively push players to peak physical fitness. It is the role of these sports scientists and medical practitioners to draw on research and harness their experiences to help players maximise their training sessions and achieve success on the field. Injury limitation and management are key to safeguarding long-term career sustainability, and ensuring that players are available for competition, with a minimised risk of recurrent injuries (Finch and Staines, 2018b)

Cricket injury epidemiology is pivotal in guiding evidence-based injury prevention strategies implemented by sports science and medical practitioners (Finch and Staines, 2018b). Understanding the mechanism, type, and frequency of injury will help improve strength and conditioning training to help mitigate injuries across teams (Perera et al., 2019a-b). However, it is also important to identify cricket player-specific roles, i.e. bowler, batter, wicketkeeper, and all-rounder, that lend themselves to a greater risk of injury. There is a wealth of published data on elite players. However, there is a significant gap in the literature related to the understanding of the physical demands of training and injuries in female cricket players at the sub-elite and emerging levels. The lack of research in this area limits the development of individualised strategies for strength and conditioning training and injury prevention at these lower performance levels. This knowledge gap is critical to understand to ensure that the progression of the next generation of professional female cricket players is not impeded.

1.2 Problem statement

This thesis aims to address evident problems in sports science and medicine for female cricket players, particularly those arising from the recent increase in interest, participation, and investment in women's cricket. The growing professionalism among female cricket players requires support from applied sports science and sports medicine (SSSM) clinicians. However, this increased involvement and professionalism are hindered by a significant lack of research, particularly on female cricket players (Bullock et al., 2022; Perera et al., 2018a), making it difficult for clinicians to find evidence-based approaches to improve the well-being and performance of female players.

Existing cricket research has predominantly focused on male cricketers, primarily elite male athletes. Most injury prediction and epidemiology studies highlight patterns observed mainly among male cricket players. Recent SSSM literature from other sports codes has emphasised that player workload, injury predisposition, and epidemiology differ between male and female athletes. Therefore, specific research is urgently needed in cricket to explore the physical profile, injury incidence, and biomechanics of female cricket players.

This thesis highlights essential research gaps in women’s cricket, including women’s health, injury prevention, and performance factors. The lack of research hinders clinicians from effectively guiding clinical practice and underscores the pressing need

for focused investigations on the specific challenges encountered by female cricket players. The papers in this thesis aim to address these challenges by mapping available research and exploring physical profiles, injury incidence, and biomechanics specific to female cricket players.

1.3 Aims and research questions

The overall theme of this thesis was to describe the biomechanical bowling action, the physical profiles of each unique player role and the injury incidence for female cricket players. This thesis further aimed to undertake a comprehensive research programme to map the available evidence and identify priority research areas in women's cricket. The aims and objectives of each study included in this thesis will be listed at the start of each chapter.

1.3.1 Aim

This thesis aimed to describe the biomechanical bowling action, the physical profiles of different player roles, and the injury incidence for female cricket players while also identifying key areas for future research in women's cricket.

1.3.2 Research Questions:

1. What does the existing sports science and medicine evidence reveal about female cricket players?

2. What are the primary areas of future research for female cricket players in sports science and sports medicine?
3. What do the physical profiles of female cricket players entail?
4. What is the injury profile observed in female cricket players?
5. What are the biomechanical differences between male and female pace bowlers?

It was essential to understand the physical profiles of female cricket players and then determine the effects of these profiles on the incidence and prevalence of injury in sub-elite women's cricket. Based on the findings of these key areas, the next step was to determine the biomechanical differences between the bowling techniques of male and female cricket players. The findings of this research programme will uniquely contribute to the knowledge bank that sports science and sports medicine teams draw on when preparing sub-elite cricket players for elite-level cricket.

1.4 Objectives of each chapter

Chapter 3 (Paper 1): The objective of this study was to map the available evidence and identify research gaps and priority areas for future investigation in sports science and sports medicine for female cricket players.

Chapter 4 (Paper 2): The objective of this paper was to describe the physical profiles of female cricket players.

Chapter 5 (Paper 3): The objective of this study was to establish the incidence and prevalence of injury in sub-elite women's cricket.

Chapter 6 (Paper 4): The objective of this study was to determine the differences in biomechanics between elite male and female pace bowlers.

1.5 Significance of each chapter

Chapter 3 (Paper 1): Practitioners in applied SSSM play a crucial role in enhancing the well-being and performance of athletes engaged in professional sports. Notably, women's cricket has recently experienced a surge in participation, support, and investments. Applied SSSM professionals are integral support staff members for numerous professional teams, both at the national and international levels. Female athletes, distinguished by their unique physiology, physical characteristics, biomechanics, and health and injury profiles, present a distinct set of challenges. Given the evident hormonal and physiological disparities between males and females, it becomes apparent that findings from studies on men's cricket cannot be indiscriminately applied to their female counterparts and vice versa. The scoping review assumes paramount significance as it is poised to provide insightful findings for coaches and applied SSSM staff working with female cricket players. These findings, grounded in evidence, will serve as a compass for making informed decisions regarding specialised interventions. Professionals in applied sports science and sports medicine are vital for improving the health and performance of athletes in professional

sports. It's worth highlighting that women's cricket has seen a notable increase in participation, support, and investments recently. In essence, the scoping review emerges as a pivotal tool in advancing evidence-based strategies tailored to the unique needs of women in cricket.

Chapter 4 (Paper 2): Ensuring athletes are optimally prepared for peak performance is contingent upon a thorough understanding of physical preparation. The existing body of research on this subject, as outlined in the applied SSSM review in **Ch. 3, pg. 41,** has become a foundational resource. However, the current landscape reveals a notable gap in our understanding of physical preparation and individualised physical profiles. Closing this research gap is imperative as it is key to advancing our knowledge and refining existing physical preparation interventions. By delving into the distinct physical profiles of all-rounders, batters, and bowlers, we gain valuable insights that could potentially inform a more individualised approach to player training. This study addresses a critical research gap and provides insights into tailoring physical preparation strategies to the unique requirements of each player type. Consequently, this player-specific approach can potentially guide SSSM practitioners working with female cricket players, ensuring that players are optimally prepared for the demands of their specific roles in the game.

Chapter 5 (Paper 3): An in-depth exploration of injury incidence and associated risk factors in sub-elite female cricket players holds profound significance in the realm of player welfare, performance enhancement, and the sustained viability of their careers.

The ability of sub-elite female players to ascend to the elite echelons hinges crucially on their freedom from injuries and consistent match availability, allowing them to showcase their skills on a broader stage. Unfortunately, a conspicuous research gap in this domain is highlighted in the applied SSSM review in **Ch. 3, pg. 41,** emphasising the scarcity of studies focused on injury incidence and prevention specifically tailored to sub-elite female cricket players. The findings of this study offer a valuable resource for applied SSSM practitioners, equipping them with evidence-based insights to formulate and implement targeted injury prevention strategies. By applying this knowledge, practitioners can significantly improve the presence and performance of sub-elite female cricket players. This proactive approach not only benefits the players' well-being in the short term but also has the potential to positively influence their career paths, making it easier for them to transition smoothly to elite levels of competition.

Chapter 6 (Paper 4): Studying pace bowling in cricket is extremely important, primarily because executing an unconventional action requires exceptional skills and specific physical characteristics. With the growing popularity and professionalism of women's cricket, female pace bowlers' roles have become critical to the success of their teams. Applied SSSM practitioners are critical in understanding female pace bowlers' intricate biomechanics and anthropometrics. This understanding is critical for increasing players' availability and enabling them to perform at their absolute best. The findings of this study have the potential to provide valuable insights that will inform applied SSSM practices in talent identification, injury prevention, and performance enhancement for female pace bowlers. A significant barrier to developing evidence-based coaching and training plans for this demographic is the lack of extensive

research into the biomechanics of female pace bowling. To address this gap and lay the groundwork for more effective strategies designed to enhance their performance, it is crucial to thoroughly examine the biomechanics and anthropometrics specific to female pace bowlers.

1.6 Structure of the thesis

This thesis is comprised of six chapters. The overviews clearly identify all authors and their proportion and type of contribution to the four published studies (Chapter 2 – Chapter 5) included in this thesis. **Figure 1-1 (pg. 10)** illustrates the conceptual map of this thesis, highlighting the progressive nature of the research programme through the publication of the four central chapters.

Chapter 1 presents the preface with the aims and objectives of this thesis. **Chapter 2** presents a general introduction to women's cricket, providing an overview of the requirements for physical preparation for the game and a profile of injury epidemiology.

Chapter 3 (Paper 1) is a scoping review. It examines the current level of evidence on applied sports science and sports medicine in women's cricket and identifies priority research areas in women's cricket. This paper identified physical preparation and injuries as key focus areas for research.

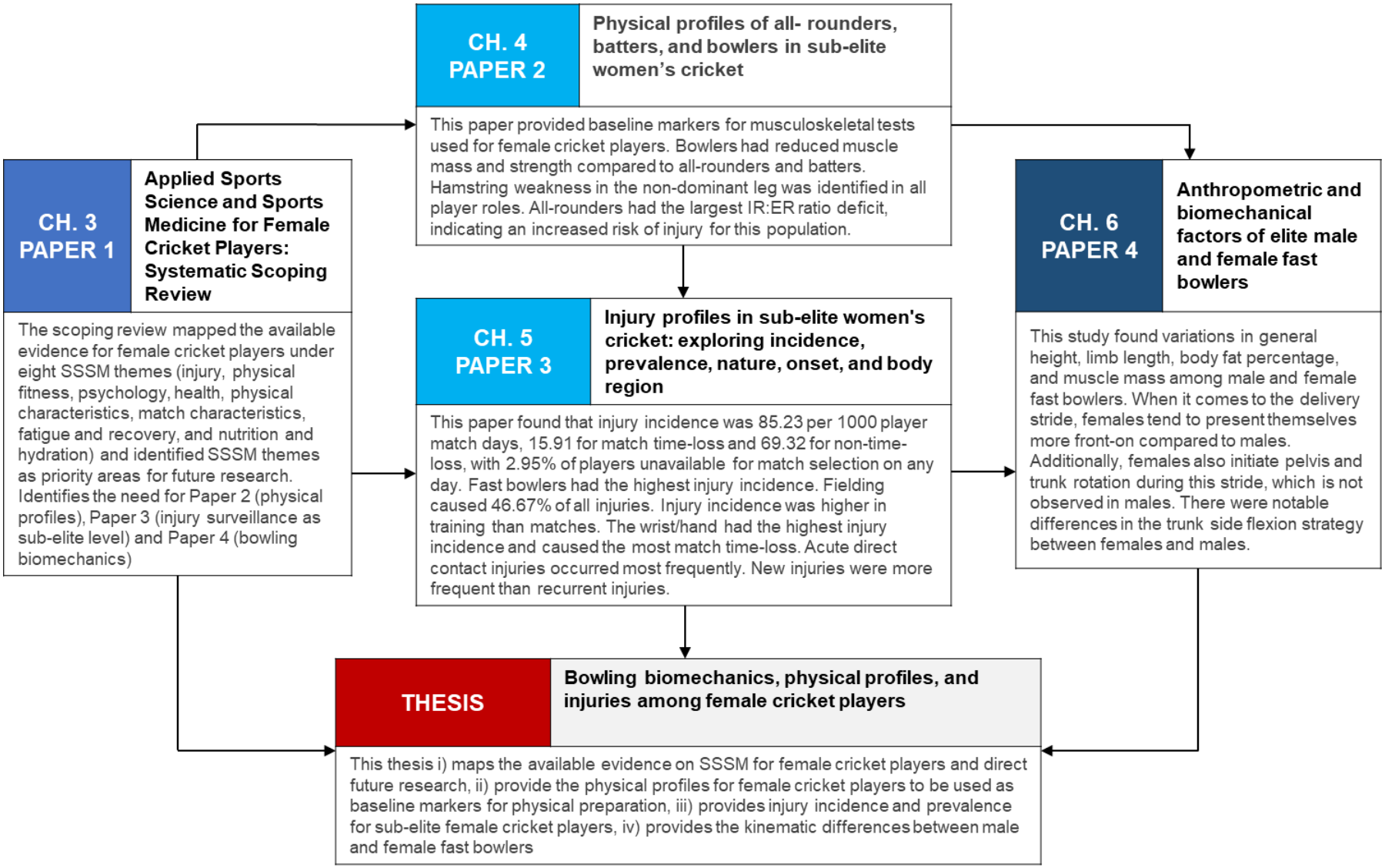

Figure 1-1: Conceptual mapping of the thesis illustrating the evolution of the research programme

Chapter 3 (Paper 1) is under second round of review at the Journal of Sports Sciences.

Jacobs, J., Olivier, B., Brandt, C., Grobler, N., Saw, A. (2024). Applied sports science and medicine in women's cricket: a systematic scoping review.

Author	Contributions
Jolandi Jacobs	Conceptualisation, Methodology, First reviewer, Writing - Original Draft.
Benita Olivier	Conceptualisation, Methodology, Supervision, Third reviewer, Writing - Review & Editing.
Corlia Brandt	Conceptualisation, Supervision, Writing - Review & Editing.
Nico Grobler	Second reviewer, Writing - Review & Editing.
Anna Saw	Methodology, Writing - Review & Editing.

Chapter 4 (Paper 2) examines the physical profiles of all-rounders, batters, and bowlers in sub-elite women's cricket.

This study provides practitioners with evidence to monitor for differences in the physical profiles of all-rounders, batters and bowlers (spin and pace). This study also facilitates the identification of strengths and weaknesses of each player role, including

identifying injury risks and enabling the optimisation of individual goals within current physical preparation programs.

Chapter 4 (Paper 2) is published in the Journal of Strength and Conditioning Research **(Appendix A).**

Jacobs, J., Olivier, B., Brandt, C., & Jafta, G. (2024). Physical Profiles of All-Rounders, Batters, and Bowlers in Sub-Elite Women's Cricket. Journal of Strength and Conditioning Research, 38(6), 1095–1102.

Author	**Contributions**
Jolandi Jacobs	Conceptualisation, Methodology, Investigation, Formal analysis, Writing - Original Draft.
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Therefore, in **Chapter 5 (Paper 3),** the injury profiles in sub-elite women's cricket were considered by exploring incidence, prevalence, nature, onset and body region, with bowlers also being the most prone to injury. Currently, injury prevention strategies are based on evidence obtained at the elite level or from research on male cricket players. Findings from this study will guide injury prevention strategies and provide relevant information to stakeholders at the sub-elite level.

Chapter 5 (Paper 3) is published in Physical Therapy in Sport **(Appendix B).**

Jacobs, J., Olivier, B., & Brandt, C. (2024). Injury profiles in sub-elite Women's Cricket: Exploring incidence, prevalence, nature, onset and body region. Physical Therapy in Sport, 67, 125–130.

Author	**Contributions**
Jolandi Jacobs	Conceptualisation, Methodology, Investigation, Formal analysis, Writing - Original Draft.
Benita Olivier	Conceptualisation, Supervision, Writing - Review & Editing.
Corlia Brandt	Conceptualisation, Supervision, Writing - Review & Editing.

To fully understand the implications of physicality and injury on bowlers, **Chapter 6 (Paper 4)** compared the biomechanics of bowling between males and females. An inertial measurement system gathered three-dimensional biomechanical data from 20 elite pace bowlers, including body segment lengths, mass, body fat, and muscle mass. Understanding these differences could lead to a more individualised approach to tailored training programs and injury prevention strategies for both male and female pace bowlers.

Chapter 6 (Paper 4) is published in the Journal of Biomechanics **(Appendix C).**

Jacobs, J., Olivier, B., Brandt, C., & Boulle, N. (2024). Anthropometric and biomechanical factors in elite male and female fast bowlers. Journal of Biomechanics, 170, 112157.

Author	Contributions
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Benita Olivier	Conceptualisation, Methodology, Investigation, Supervision, Writing - Review & Editing.
Corlia Brandt	Conceptualisation, Supervision, Writing - Review & Editing.
Nathanael Boulle	Formal analysis, Writing - Review & Editing.

Chapter 7 provides a summary and synthesis of the findings of the entire research programme and considers the impact of this research on the broader community of sub-elite female cricket players. This chapter also describes the strengths, limitations and practical implications of this research and provides suggestions for future research and a conclusion.

Appendices related to this research presented in this thesis follow the **references.**

CHAPTER 2. LITERATURE REVIEW

The literature review provides a background of cricket and the participation of females in cricket and links this with the aims and objectives of this thesis. The literature review discusses the history of women's cricket and the development of women's cricket in recent years. The literature review also introduces sports science and medicine topics in women's cricket and how these topics link to the aims and objectives of each chapter. The literature review provides a brief introduction to this thesis and is followed by a comprehensive scoping review on sports science and sports medicine for female cricket players in **Ch. 3, pg. 41.**

2.1 History of women's cricket

Women's cricket has had an extensive history, with the first official cricket match played in the early 1700s (Guttman, 1991), however, the establishment of the inaugural International Women's Cricket Association in the United Kingdom (UK) in the 1900s marked the first step towards provision of a professional environment for women's cricket (Frewin, 1986). Australia, New Zealand, and the Netherlands followed the UK and established national women's cricket organisations to support the professional development of their players. The first International Women's World Cup was played in England in 1973 and provided competitive global competition for elite players (Odendaal, 2011). In 1985, the International Women's Cricket Council was established to lead professional development on a global scale, which then merged

with the International Cricket Council (ICC) in 2005 to form a unified international governing body for both men's and women's cricket (Velija, 2015). Another significant highlight in the history of women's cricket was the first ever twenty-twenty (T20) match between England and New Zealand in 2004. This led to the establishment of the ICC Women's World Twenty20 Championship in 2019, which provided further opportunities for female cricket development.

Since the inception of professional cricket, female cricket players have been setting benchmarks despite the widespread perception that men's cricket is the predominant game (Hickey et al., 2016). Women have recorded some impressive cricket milestones, for example, Christine Willes introduced the first overarm delivery in bowling, despite her brother taking credit for the invention (Odendaal, 2011). The Australian batter, Belinda Clarke, scored the first double-century in 1997 (Vishwanathan, 2020). Women's cricket also holds the record for the first five-wicket haul in a One Day International World Cup, and the Australian women's team was the first team to win five World Cups (Vishwanathan, 2020). With the development of women's cricket in recent years, it is important to investigate the factors influencing performance and wellbeing of players. This involves investigating the current physical and injury profiles of female cricket players.

In recent years, there has been a notable increase in participation, popularity and investments in women's cricket, with players having more opportunities to participate in cricket at school, junior, club, state, and national levels (Jolly, 2021). Australia has

reported a total of 50,000 registered female participants in cricket clubs nationwide (Cricket Australia, 2023a). The competitive nature of shorter cricket formats, such as T20 cricket, has gained significant popularity globally among female players and supporters (International Cricket Council, 2023). The rise of female cricket players participating in shorter formats is evident at junior and senior club levels (Shah, 2018). The increased endorsement of women's cricket has enabled junior female cricket players to pursue a full-time career playing cricket (Healy, 2020; Garcia-Byrne et al., 2020).

Recent financial investments in women's cricket have enabled full-time contracts for players to earn a salary when competing domestically and internationally (Jolly, 2016). In addition, professional cricket governing bodies, such as the England Cricket Board and Cricket Australia, have committed substantial financial resources to support the advancement of women's cricket from junior to senior levels (Jolly, 2016; SkySports, 2020). Other cricket nations have also taken significant strides in offering female cricket players part-time or full-time contracts to address the disparity between state and national levels.

Finally, most nations offer full-time national contracts to female cricket players at national levels with the same remuneration as national male cricket players (Moonda, 2023). Several international professional leagues, such as the Women's Indian Premier League, Women's Big Bash League, The Hundred, and Fairbreak, provide players with opportunities to participate at the highest levels and receive substantial

remuneration on top of their domestic or national contracts (Australian Cricketer's Association, 2023). To conclude, women's cricket has evolved from amateur recreational to competitive professional sports. The demand for matches and training intensifies when a sport evolves into a competitive professional format.

2.2 Overview of the game of cricket

Cricket is played as two teams, with 11 players each, competing in a cricket match. Each team has specific player roles, such as batting, bowling, fielding and wicketkeeping. Each role serves a distinct function and is integral to a competitive match (Petersen et al., 2010). During a match, the batting team has two batters at the crease, while the bowling/fielding team has 11 players on the field (Eastaway, 2016).

A bowler is a player who delivers a ball to the batter using a legal bowling action according to international cricket rules (Orchard et al., 2016). Bowlers can be sub-grouped into fast/pace, fast-medium, medium, and spin/slow bowlers. The terms "fast" and "fast-medium" bowlers are often combined and referred to as “pace bowlers” (Orchard et al., 2016). Most pace bowlers usually deliver the ball at higher speeds using a longer run-up in comparison to spin bowlers who bowl using slower speeds and shorter run-ups (Felton et al., 2019). Medium-paced bowlers deliver the ball at a slower rate than pace bowlers but quicker than slow or spin bowlers. Female pace bowlers have similar run-up speeds to male pace bowlers but have slower ball release speeds (Savage and Portus, 2002a; Bartlett et al., 1996). Female pace bowlers have

an average ball release speed of around 120 km/h, compared to males who bowl around 140 km/h (Munro, 2019a).

The term 'batter' is considered a more inclusive term than 'batsman' and is the recommended term in cricket (Burnton, 2021). Batters wear protective gear and use a cricket bat to score runs while facing deliveries from the bowler (Stretch, 2006). The batting team concludes each innings when they reach the overs or time limit or when the bowling team takes ten wickets. When a bowler, fielder, or wicketkeeper gets a batter out, a new batter takes their place at the wicket (Eastaway, 2016). The batting team seeks to maximise their run count throughout their innings, whereas the bowling/fielding team strives to restrict the batting team's runs and secure ten wickets to conclude the innings. Ultimately, the team with the highest run total after two innings win the match.

All-rounders in cricket can perform both batting and bowling skills as required by the team’s captain and are typically categorised into batting or bowling all-rounders, depending on their predominant skill (Manage et al., 2020). The adaptability of all-rounders is crucial, as it enables them to perform for their team by either scoring runs with the bat, taking wickets, or limiting runs scored with the ball.

The fielding/bowling team has one bowler at a time who delivers six legal balls, concluding an over. The remaining ten players are fielders and support the bowler in limiting the runs scored by the batters. Fielders can secure wickets by catching the

ball or executing a run-out to dismiss a batter (Eastaway, 2016). The wicketkeeper plays a crucial role in the fielding team and is positioned behind the wickets on the opposite side of the bowler's delivery (Orchard et al., 2016). The wicketkeeper assists the fielders and bowlers to take wickets or limit the runs scored by the batter. Fielders and wicketkeepers must display agility by jumping or diving from their designated positions to field the ball and restrict the batting team's winning chances (Robert et al., 2014).

2.3 Length of cricket matches

Cricket players participate in one-day or multiple-day matches. Firstly, there are multi-day formats, such as test match cricket, consisting of two-innings per team spanning over several days with no limit on overs bowled per team (Orchard and Finch, 2002). Male cricket players participate in test matches over five days, while female cricket players typically play test matches over four days (Harris, 2005), however, recent developments have extended women's test matches to five days. Another format is the one-day match, a single-innings match with 50 limited overs per team (Orchard et al., 2016). The Twenty20 (T20) format is the most recent and thrilling addition to cricket matches and consists of a single innings, with each team restricted to 20 overs. **Table 2-1** summarises the match schedule tailored for women's cricket.

Table 2-1: The schedule for women's cricket matches

	One-innings match (50 overs)	One-innings match (20 overs)	Two-innings match
Match between international teams	One-day international (Limited to 50 overs)	Twenty20 international match (limited to 20 overs)	Test match (Limited to 4/5 days*)
Match between non-international teams of the same country	Domestic one-day match (Limited to 50 overs)	Domestic one-day match (Limited to 20 overs)	First-class domestic match (Limited to 4/5 days*)
Match between two first-class teams (other)	Other List A one-day match (Limited to 50 overs)	Other List A one-day match (Limited to 20 overs)	Other first-class match (Limited to 4/5 days*)

*Adapted from Orchard et al. (2016) and *Harris (2005).*

2.4 Levels of play in women's cricket

Females play cricket at different levels, from recreational (unprofessional) to elite (professional). Recreational cricket is popular at the grassroots, including both competitive and non-competitive forms of the sport. Recreational cricket is a leisurely activity for personal enjoyment and the establishment of the "Spirit of the Game" (Cricket Australia, 2015). Recreational cricket also includes indoor cricket, played at professional and recreational levels. There has been an observed spike in the number of women playing indoor cricket (Cricket Australia, 2022). Indoor cricket also provides an opportunity for women in cold countries to continue playing cricket during the winter season.

Community cricket offers a range of opportunities for recreational players to enhance their skills, play for fun, and foster inclusivity among all individuals. Community cricket is played at recreational areas, schools, and organised clubs. Participation numbers for community cricket are a catalyst for the development and growth of cricket (Cricket Australia, 2023a). Junior-level cricket includes the participation of individuals who engage in competitive events organised within schools or clubs. Junior players have opportunities to compete in tournaments, with teams usually grouped as under 13 years (U13), under 15 years (U15), and under 18 years (U18). The primary objective of these competitions is to foster active engagement among junior cricket players within an enjoyable environment (Cricket Australia, 2014). Cricket Australia's yearly update for 2023 reported that participation numbers have increased in recent years, with a 4% rise in registered participants in cricket clubs, totalling 409,642, and a consistent 108,100 registrations in junior club cricket. Additionally, there has been an 11% increase in registrations among children aged 5-12, reaching 129,000, and a significant rise in participation among South-Asian girls and boys aged 5-12, with increases of 60% and 16%, respectively (Cricket Australia, 2023a).

Club cricket involves junior or senior players in a competitive league (Eastaway, 2016) and allows players to showcase their skills by competing against other skilled players. A census in the United Kingdom reported that 63,000 females aged 14 years and above are actively involved in club-level cricket (England Cricket Board, 2013). The Women's County Championship, an annual cricket tournament held in England, features 36 teams competing in a 50-over format (Shah, 2018).

The state, domestic, or provincial level provides a platform for skilled players to showcase their abilities in organised and competitive matches and training sessions. The participation of women at the state level contributes to the overall advancement and development of these players, serving as a platform for the identification of talented individuals for potential national team selection. Furthermore, pathway programs and national academy teams, such as the Australian Cricket Talent Pathway and the England and Wales Cricket Pathway, provide an optimal platform for talent identification for national team selection.

Elite-level cricket includes the participation of players who engage in competitive matches at the highest levels, typically playing test matches, one day internationals (ODI) and T20 matches and representing their nations against other international squads (International Cricket Council, 2023). Several international professional leagues, such as the Women's Indian Premier League, Women's Big Bash League, The Hundred, and Fairbreak, provide players with opportunities to participate at the highest levels and receive substantial remuneration on top of their domestic or national contracts (Australian Cricketer's Association, 2023).

2.5 Introduction to sports science and medicine (SSSM)

2.5.1 Sports science and medicine in women's cricket

For female cricket players to perform at their peak, applied sports and applied sports science and medicine (SSSM) practitioners need to plan and prescribe appropriate methods for the overall well-being of players. The evidence-based knowledge in this area is growing, particularly related to injury, performance, and well-being of players (Letter et al., 2022a; Jacobs et al., 2022) with the aim of identifying optimum performance strategies for cricket players.

The musculoskeletal system and a technical skillset are essential in different aspects of cricket, especially during batting, bowling, or fielding, such that athletes must execute rapid direction changes and sustain strength and equilibrium to perform their specialised skills during all cricket activities. Published data has indicated that many physical characteristics, including body composition and muscle strength, may significantly impact the performance of cricket players (Dutton et al., 2019; Wormgoor et al., 2010).

Applied SSSM is a multidisciplinary field, including sports physicians, physiotherapists, physical performance coaches, dietitians, sports psychologists, biomechanics, and sports scientists (Cricket Australia, 2023b). The team comprises professionals with undergraduate or postgraduate degrees in their respective fields,

all with roles that prioritise the maximal physical and mental preparation of female cricket players to achieve peak performance. Additionally, the SSSM team has a role in optimising player availability during matches to enhance the likelihood of achieving success for a team at all levels.

Evidence-based findings from researchers provide applied practitioners with the relevant knowledge to make well-informed decisions regarding applied SSSM practices. Research projects in the field of applied SSSM typically encompass areas such as injury epidemiology and prevention (Jacobs et al., 2022), as well as physical preparation (Letter et al., 2022a) and wellness (Ely et al., 2023). Various national cricket boards, including Australia and South Africa, possess national data housing software that serves as a centralised repository for all information on the applied SSSM of their players. This software is crucial in providing data for research on applied SSSM (Cricket Australia, 2023b). The dissemination of research findings typically involves sharing them with all members of the applied SSSM from elite to grassroots levels and subsequently translating the research into community guidelines to facilitate effective cricket engagement at all levels of the cricket.

2.5.2 Anatomical differences between male and female cricket players

Several research studies have identified anthropometric differences between male and female athletes across various sports, indicating that optimal performance often depends on specific physical traits and characteristics (Koley and Kashyap, 2010a;

Claessens et al., 1999; Gabbett, 2000). These differences stem primarily from variations in body composition, skeletal structure, and muscle distribution influenced by biological and hormonal factors (Gabbett, 2000; Claessens et al., 1999). Elite male fast bowlers typically have greater muscle mass and lower body fat percentages compared to their female counterparts, who tend to have a higher body fat percentage and less muscle mass, impacting various physical performances (Stuelcken et al., 2007). Additionally, male bowlers often have greater length, breadth, and girth measurements, while female bowlers display higher endomorphic and lower mesomorphic characteristics (Stuelcken et al., 2007).

The skeletal structure differences between male and female cricket players also significantly influence performance. For instance, female fast bowlers generally have proportionally longer trunk lengths than males, which could provide a biomechanical advantage by allowing them to use right-to-left trunk side flexion to generate momentum during the delivery stride (Jacobs et al., 2024). Conversely, male bowlers with greater shoulder-to-wrist and total arm lengths may achieve higher ball release speeds (Glazier et al., 2000). Moreover, height-related variables, such as shoulder height, arm span, hip height, and knee height, demonstrate considerable distinctions, with males consistently displaying larger measurements. These anatomical differences can affect the biomechanics of both bowling and batting, influencing factors such as ball release speed and the ability to generate power in shots (Pote et al., 2023a).

Muscle distribution and joint flexibility also vary between male and female cricketers, impacting shoulder mechanics and injury risk (Dutton et al., 2019; Stuelcken et al., 2010a). Shoulder distraction forces can lead to microtrauma within the shoulder joint due to the demands they place on the rotator cuff, labrum and surrounding structures, increasing the risk of injury during throwing and bowling (Nebel et al., 2023; Stuelcken et al., 2010a). Additionally, greater joint laxity, and less upper body muscle mass in female cricket player and a combination of shoulder distraction forces, increasing the risk of shoulder injuries (Stuelcken et al., 2008b; Beerworth et al., 2022b). This difference in muscle composition not only affects performance but also influences injury risk profiles, with males being more susceptible to muscle strains and females more prone to ligament injuries due to joint laxity and anatomical structure (Hewett, 2000b).

Females typically have a wider pelvis and an increased Q angle, affecting lower limb biomechanics and leading to different movement patterns that raise the risk of knee and hip injuries compared to males (Medina McKeon and Hertel, 2009; Mohamed et al., 2012). These anatomical and biomechanical differences emphasise the importance of recognising that findings from male cricket studies may not directly apply to female cricket players. In conclusion, male and female cricket players have significant anthropometric differences, impacting their physical profiles, injury profiles, and biomechanics. These distinctions highlight the need for more targeted, sex-specific research to ensure training and injury prevention strategies are optimised.

2.5.3 Injury definitions and standardised reporting

Increased participation in cricket increases injury risk. Injuries reduce short- and long-term sports participation, training, match performance, health benefits, and player well-being (Bullock et al., 2021). Maximising training and match availability improves player and team performance and success, whereas injury limits player and team performance (Drew et al., 2017; Hägglund et al., 2013; Raysmith and Drew, 2016). Severe injuries can impact sports careers, with some injuries terminating careers (Ristolainen et al., 2012). In addition, players who sustained a previous injury are more likely to get recurrent injuries (Hägglund et al., 2006). As a result, injuries sustained by female cricket players during their pre-elite years may impact future injury risk and long-term health implications (Bullock et al., 2020b). These findings suggest that early sports injuries could lead to premature degenerative changes, underscoring the importance of effective injury prevention and management strategies for female athletes.". Applying injury management measures can improve female cricket players' engagement at all play levels and their capacity to progress to the elite levels.

Various injury prevention models, including the Translating Research into Injury Prevention Practice (TRIPP) framework (Finch, 2006), were developed to provide a structured approach for sports stakeholders to reduce the risk of injuries. The initial phase of the TRIPP model is to create a descriptive injury profile of the population, commonly referred to as injury epidemiology. Subsequently, injury epidemiology will guide the next stage of the injury surveillance framework (Finch, 2006).

Epidemiological data can provide valuable insights to relevant stakeholders regarding injury rates, nature, body regions, player roles, and injury-related activities. Further, this information can inform the development of evidence-based injury prevention strategies to be implemented in practice.

Epidemiological evidence suggests that factors related to injury differ between the sexes due to physiological factors (Lin et al., 2018; MacCormick et al., 2014). Female athletes sustain more injuries than male counterparts (Ericksen and Gribble, 2012). Hormone variations linked with the menstrual cycle and joint laxity increase females' risk of injury and affect performance (Hewett, 2000a). Furthermore, due to the variations in factors such as bowling pace, skills, training and match schedules (Koley and Kashyap, 2010b; Stuelcken et al., 2007) it is not appropriate to generalise evidence from male to female cricket players (Perera, 2016b; Stuelcken et al., 2007). Injury prevention for male cricket players is inapplicable to strategies to reduce injuries in women's cricket.

Available and injury-free players are essential for individual and team success (Drew et al., 2016). Injury prevention strategies are needed to optimise player performance and to reduce medical attention and time-loss injuries (Perera et al., 2019a-a). Injury prevention strategies aim to identify and reduce injuries by addressing musculoskeletal factors associated with injury risk (Perera et al., 2019a-a). Injury surveillance is essential for monitoring and preventing injuries in athletes across various sports (Finch and Staines, 2018a; Finch, 2006). Injury surveillance is a

systematic approach to identifying and analysing injury risks, types, causes, and relevant associated factors. The initial step in injury prevention includes establishing injury surveillance systems to identify high-risk areas for injuries (Ranson et al., 2013). The International Consensus Statement provides injury definitions to guide injury surveillance in cricket.

Standardised injury definitions and reporting methods enable the comparison of injury data across various sexes and sports (Junge et al., 2008). Injury surveillance in cricket will offer valuable insights for long-term development, data collection, and effective injury prevention strategies. The Orchard Sports Injury Classification System (OSICS) directs the methodology and data capturing for injury diagnosis and medical care. The OSICS, a four-character system, is utilised by numerous international sporting organisations (Finch et al., 2014).

The International Olympic Committee (IOC) assembled a group of experts in 2020 to conduct a thorough review that included surveys, drafting, and consultation, resulting in the development of guidelines covering various aspects of health problem definition, severity, athlete exposure, risk expression, and data collection methods (Bahr et al., 2020). The goal was to improve data collection and reporting uniformity by providing updated recommendations, including a checklist extension called Strengthening the Reporting of Observational Studies in Epidemiology – Sports Injury and Illness Surveillance (STROBE-SIIS). The IOC encourages ongoing surveillance programs to

comprehend and address injury and illness trends, and following these guidelines will improve research reporting consistency.

Soon after the 2020 IOC consensus statement was released, a consensus working group of five experts in sports medicine, epidemiology, and female athlete health identified vital themes to expand the IOC consensus statement (Isabel et al., 2023). The extension covers ten domains of female health, including menstrual health, pregnancy, mental health, and other topics. This extension of the IOC consensus statement aims to improve the quality of epidemiological studies by providing data capture recommendations for female athlete population characteristics, injuries, illnesses, and other health issues. The goal is to inform better prevention strategies for injuries and illnesses in female athletes at various stages of life (Isabel et al., 2023).

Continuous injury surveillance is essential for effective injury prevention as it helps identify the characteristics, risk factors, and causes of injuries. Several countries do not have official sports injury surveillance systems and face challenges in terms of injury diagnosis and medical services, which are essential for players to meet the demands of the game (Hickey et al., 2016). Injury surveillance is essential for implementing proper medical management in athletes (Ranson et al., 2013). Medical personnel working with sports teams are essential in managing and preventing player injuries. Limited access to medical staff can delay injury diagnosis and negatively impact player management (Perera et al., 2018b). Research also suggests that

applied SSSM should direct their attention to areas with the highest injury risk and ensure that players receive appropriate medical support (Ranson et al., 2013).

2.5.4 Evidence gap in applied sports science and medicine research

Research into applied SSSM for women's cricket has doubled in the last decade (Jacobs et al., 2022; Perera et al., 2017b; McErlain-Naylor et al., 2021; Felton et al., 2019). However, similar to research in other women's sports, evidence-based information for female athletes is scarce due to a lack of interest and investment in the past years. As a result, applied SSSM practitioners have to use research findings from male athletes directly on female athletes. For instance, before the investigations conducted by Stuelcken et al. (2010b), the biomechanics of female pace bowling were approached similarly to male cricket players without specific consideration for differences between the sexes. Also, before reporting injuries in female cricket players (Perera et al., 2019a-a; Warren et al., 2019), injury prevention protocols for female cricket players were similar to those for male cricket players.

The discrepancies between male and female cricket players contradict the direct polarisation of applied SSSM research findings from one sex to another (Felton et al., 2019; Perera, 2016b). Hence, implementing and evaluating applied SSSM strategies is essential for the performance of female cricket players. For applied SSSM to make evidence-based decisions for female cricket players, research into physical preparation, including the musculoskeletal system and overall health, is required for

the desired performance outcomes. It is essential to acknowledge the significant progress made by applied SSSM in women's cricket over the past decade; however, evidence-based applied SSSM practices are still scarce and should be a priority for future research.

2.6 Physical profiles of female cricket players

2.6.1 Physical demands of female cricket players

There are observed physical demands between playing positions (Weldon et al., 2021; Johnstone and Ford, 2010). The diverse demands and physical capacities of each player are unique to their specific role in a team (Weldon et al., 2021). The lack of existing research on the physical profiles of female cricket players, particularly those besides pace bowlers, is evident. This dearth of information highlights the limitations of current sports science and medicine approaches in women's cricket. Extrapolating research findings from men's cricket or elite female pace bowlers to all levels of female cricket players is not scientific and raises valid concerns. Comprehensive findings regarding the physical demands of certain playing positions would be vital for developing and informing strength and conditioning principles to enhance the physical preparation of female cricket players (Weldon et al., 2021). Various physical parameters such as body composition, muscle strength, and aerobic fitness must be evaluated to investigate the differences between individual player roles.

The physical qualities of individuals improve with years of playing cricket. Letter et al. (2022b) found that older female pace bowlers had higher absolute and relative force measures in the isometric midthigh pull and strength in the one-repetition maximum bench pull tests. The results showed that most of the female pace bowlers' physical traits improved with age due to the training effect and should lead to a gradual increase in ball release speed. Letter et al. (2022a) also found that the isometric midthigh-pull, one-repetition maximum bench pull strength and run-of-3 performance of faster female pace bowlers differed from slower pace bowlers. Letter et al. (2022a) further suggested that anaerobic dominant physical traits are essential for the performance of female pace bowlers. The effect of these physical characteristics on ball release speed between faster and slower female pace bowlers seems to be directed by lower body strength, relative anaerobic capacities, and upper body strength.

2.6.2 Physical profiles of batters, bowlers and wicketkeepers

It is essential to understand the physical profile of players to develop physical preparation guidelines in cricket. Physical preparation guidelines are widely researched in men’s cricket (Weldon et al., 2021), including physical profiling for individual player roles such as bowlers and batters (Johnstone and Ford, 2010). The same is not evident for women’s cricket as current research supporting physical preparation for female cricket players focuses on female players as a group (Murphy et al., 2020) or explores the profiles of elite pace bowlers (Stuelcken et al., 2008a; Letter et al., 2022a; Letter et al., 2022b). Letter et al. (2022a) found that faster female

pace bowlers possess superior physical characteristics, such as maximal upper body muscle strength, compared to slower pace bowlers. However, there was no difference in CMJ height among the faster and slower female pace bowlers (Letter et al., 2022a). Letter et al. (2022b) found changes in physical profiles between different age groups but no changes for seasonal assessments. Letter et al. (2022a) suggested that improving lower body strength, anaerobic capacities, and upper body pulling strength may enhance performance in female pace bowlers. Murphy et al. (2020) found a dominant arm internal rotation:external rotation strength deficit ratio in female cricket players and linked this with a 1.79 times increased risk of shoulder injury.

Differences exist between the physical profiles and demands among various player roles (Weldon et al., 2021; Johnstone and Ford, 2010). Identifying individual shortcomings and tailoring approaches to the sub-roles in cricket is crucial, considering each player's diverse demands and physical capacities (Weldon et al., 2021). The lack of existing research on the physical profiles of female cricket players, particularly those besides pace bowlers, is apparent. This dearth of information highlights the shortcomings of current sports science and medicine approaches in women's cricket. Extrapolating research findings from men's cricket and elite female pace bowlers to all female cricket players raises valid concerns. Comprehensive findings regarding the different player roles (Weldon et al., 2021) would be vital for developing and informing strength and conditioning principles to enhance the physical preparation of the female cricket player. Various physical parameters such as body composition, muscle strength, and aerobic fitness must be evaluated to investigate the differences between individual player roles.

Pote et al. (2023b) conducted a systematic review on the anthropometric and morphological characteristics of elite male cricket bowlers and batters over time and found that batters are generally shorter, lighter, and have a higher relative fat mass compared to bowlers, although these differences are not always statistically significant. Furthermore, both groups tend to have endo-mesomorphic somatotypes, but batters have slightly higher endomorphic characteristics (Pote et al., 2023b). These differences could be influenced by genetic predisposition, nutritional practices, and evolving training regimens. Physical profiles of batters, wicketkeepers and all-rounders in women's cricket are unexplored, and highlight a significant gap in the current literature. Moreover, there is a noticeable lack of research for sub-elite female cricket players.

2.6.3 Performance insights and injury considerations

The musculoskeletal system plays a crucial role in cricket, particularly in batting, bowling, and fielding. It enables athletes to make rapid changes in direction, accelerate, and maintain power and stability during gameplay. Evidence suggests that several physical factors, including body composition and muscle strength, significantly impact cricket performance (Dutton et al., 2019; Wormgoor et al., 2010). Therefore, prioritising the physical preparation of cricket players to achieve optimal performance is crucial.

It is essential to understand the physical profile of female cricket players to guide physical preparation. Physical preparation guidelines are widely researched in men's cricket (Weldon et al., 2021), including physical profiling for individual player roles such as bowlers and batters (Johnstone and Ford, 2010). The same is not valid for women's cricket as current research supporting physical preparation for female cricket players focuses on female players as a group (Murphy et al., 2020) or explores the profiles of elite pace bowlers (Stuelcken et al., 2008a; Letter et al., 2022a; Letter et al., 2022b). Letter et al. (2022a) found that faster female pace bowlers possess superior physical characteristics, such as maximal upper body muscle strength, than slower pace bowlers. However, there was no difference in countermovement jump (CMJ) height among the faster and lower female pace bowlers (Letter et al., 2022a). Letter et al. (2022b) found changes in physical profiles between different age groups but no changes for seasonal assessments. Letter et al. (2022a) suggested that improving lower body strength, anaerobic capacities, and upper body pulling strength may enhance performance in female pace bowlers. Murphy et al. (2020) found a dominant internal rotation/external rotation strength deficit ratio in female cricket players and linked this with a 1.79 times increased risk of shoulder injury.

2.7 Injury profiles in women's cricket

To report injury profiles in women's cricket, it is essential to calculate injury incidence and prevalence, which involves identifying a cohort of participants as the population of interest (Rothman, 2012). Injury incidence and prevalence in cricket are needed to understand the aetiology. In cricket, the population is called the 'squad' (Orchard et

al., 2016). The squad's size is usually a minimum of 11 players and is named at the start of the season. The coach or captain will establish the player roles at the start of the season based on the player's experience and expertise in that role (Orchard et al., 2016). To accurately calculate injury incidence or prevalence, both injured and healthy players of the same team should be included (Orchard et al., 2016). Injury prevalence is all the injured and unavailable players divided by the total squad number. Injury prevalence is quantified as a percentage and recorded with a denominator. Injury incidence should be calculated separately from injury prevalence as there are differences in exposure hours for different cricket formats, including ODI, T20, and test cricket (Orchard et al., 2016).

Injury incidence is the count of newly reported injuries, including initial and recurring ones, within a specific time frame. Injuries can occur during training and matches. Exposure hours are required to calculate match incidence and should align with the definitions of the Cricket Consensus Statement (Orchard et al., 2016). Reporting injury incidence in cricket should include a time denominator, such as injuries per overs or balls bowled for batting or bowling activities (Orchard et al., 2016). Seasonal injury incidence refers to the overall number of injuries within a team throughout a season. The seasonal occurrence of injuries should be reported using a time denominator, specifically injuries per squad per season (Orchard et al., 2016).

The International Consensus Statement provides injury definitions to guide injury surveillance in cricket (Orchard et al., 2016). This statement establishes standardised

injury definitions and guidelines as the benchmark for reporting injuries in cricket. The term "injury" is defined as an incident or medical condition that renders a player ineligible for selection in a match or limits their ability to perform batting, bowling, or wicket-keeping duties as requested by the captain or match rules (Orchard et al., 2016). The International Consensus Statement was recently updated to refine injury definitions, and categories such as amateur and junior-level cricket players and women's cricket were refined (Orchard et al., 2016).

The growing popularity and increased participation in women's cricket worldwide will likely lead to a corresponding rise in injuries (Perera, 2016b; Munro and Christie, 2018). Research on female cricket players is limited, as some countries lack injury surveillance and research strategies. Cricket profiles, playing conditions, and match scheduling methods of South Africa, New Zealand, and Australia are similar, hence, research outcomes for countries similar in cricket development structures can be reported as standard in one country and copied to another (Perera, 2016b). There is a need to establish injury surveillance systems for women's cricket in all cricket nations. It is also essential to improve the quality of current injury surveillance systems across the globe. Most injury epidemiology studies for female cricket players are from elite-level players in Australia (Perera et al., 2017a).

Female cricket players frequently sustain injuries during matches and training. A recent systematic review on injuries in female cricket players (Jacobs et al., 2022) reported that elite cricket players had 71.9 injuries per 1000 player hours, 13.3 time-

loss injuries, and 58.5 non-time-loss injuries. Injury prevalence ranged from 65.2% for community to elite cricket and 60% for community cricket. There were 5.6 injuries per 10,000 participants in community cricket. Elite cricket players exhibited a higher frequency of injuries than community cricket players. The shoulder and knee were the most injured body regions, with pace bowlers being the most affected. Fielders experienced the highest hand, wrist, and finger injuries (Jacobs et al., 2022).

Medical data from hospitals or insurance sources provide injury information at the community level. Perera et al. (2016a) investigated the incidence of injuries among female cricket players, resulting in successful insurance claims in Australia. The study revealed that most successful insurance claims (82.4%) were due to injuries sustained during competitions, particularly during batting (48%). Fielding-related injuries made up 38% of all reported claims. The body regions with the highest injury incidence were the knee (24.1%), distal upper limb (19.4%), and teeth (14.8%). The primary causes of injury were sprains (24.1%) and fractures (22.2%). The average annual injury rate was 1.26 per 10,000 registered players.

A study investigated injuries among elite female cricket players in Australia for two seasons (Perera et al., 2019a-a). Out of the 600 reported medical-attention injuries, 77.7% of players had multiple confirmed injuries. Acute injuries were 79.5% of the total injuries, time-loss injuries (requiring medical attention) were 20.2%, and match-time-loss injuries were 34.7%. The wrist, hand, lower back, and knee were the most common areas for time-loss injuries. Six players experienced lower back injuries,

which led to a significant number of days lost due to the injury, averaging 110.5 days per injury.

A retrospective analysis of cricket injury data in New Zealand from 2005 to 2016, using information from the Accident Compensation Corporation (ACC), showed that there were 9,350 injuries among female players (Walter et al., 2022b). The injury incidence rate for females was 36.1 per 1,000 participants, significantly lower than the rate for males (64.1). Although the total number of cricket-related injury claims increased by 42.6% during this period, the injury incidence rate decreased from 59.0 in 2006 to 42.8 in 2016. Injuries were most common in the hand/fingers and lumbar regions, especially during contact activities (Walter et al., 2022b).

The shoulder is at high risk of injury due to the above-the-shoulder nature of activities such as throwing and bowling (Murphy et al., 2020). Basketter (2014) conducted a study in the UK and found that the shoulder region had the highest incidence. Basketter (2014) found that pace bowlers have a higher risk of injury compared to other player roles. Bipasha et al. (2018) reported that the shoulder was the most frequently injured body region, accounting for 39.1% of the injuries. Stuelcken et al. (2010a) conducted a study on female cricket bowlers and found that the distraction force can contribute to a shoulder injury. According to Stuelcken et al. (2008b), the shoulder strength ratio of eccentric external to concentric internal rotation in female cricket players who bowl is below the recommended level for joint stability and muscle control. To reduce the risk of shoulder injuries, it is essential to design shoulder-

specific strength and conditioning pre-rehabilitation programs tailored for female cricket players (Basketter, 2014).

Injuries to the wrists, hands, and fingers commonly occur frequently in cricket due to direct impact from the ball or contact with the ground during fielding activities. Direct impact injuries often occur when a cricket ball strikes a player at high velocities. The cricket balls used in women's cricket are smaller and lighter than those used in men's cricket (Basketter, 2014). The size and weight of the cricket ball, relative to the size of the hand, may contribute to increased wrist and hand injuries in women's cricket. Research findings indicate that female cricket players exhibit lower hand-eye coordination levels than their counterparts in female handball (Paul, 2017). Female cricket players exhibited slower auditory but faster visual reaction times than female handball players. Female cricket players may have developed strategies for catching or fielding that increase their susceptibility to hand and finger injuries (Perera et al., 2019a-a). Wicketkeepers and batters wear protective gloves to reduce the severity of hand, wrist, and finger injuries (Stretch, 2006). Personal protective equipment and specialised skills training are essential for injury prevention in the wrist, hand, and finger regions.

The incidence and severity of head impacts in cricket have increased in recent years despite guidelines encouraging the use of protective gear (Hill et al., 2019; Perera et al., 2019b; Saw et al., 2020). Concussions often occur due to significant head impacts during batting (Saw et al., 2020; Warren et al., 2019). Perera et al. (2019b) discovered

that female cricket players experienced significant head impacts, leading to 27.8% of emergency department visits and 28.1% of hospital admissions. Protective gear such as helmets, pads and gloves can reduce the risk of injury, specifically head and facial injuries in cricket players (Stretch, 2006).

There are evident differences between the injury profiles of elite and sub-elite levels. Elite level cricket players are exposed to increased physical demands to meet the intensity of cricket matches (Garcia-Byrne et al., 2020) and have high injury rates (Warren et al., 2019; Perera et al., 2019a). The reduced professionalism at the sub-elite level impacts injury profiles; only a few players in sub-elite teams have formal contracts, unlike the full-time contracts common at elite levels. This lack of professional contracts and financial support means sub-elite players often juggle cricket with other work and personal commitments, resulting in less frequent and less intense training, which could lower injury risk. Furthermore, sub-elite players are generally younger and have less experience and exposure to skill development compared to their elite counterparts, limiting their physical capacity and potentially reducing injury risk due to the reduced physical demands at the sub-elite level (Kelly et al., 2019). Given these differences, research at the sub-elite level is crucial to understanding unique risk factors, such as bowling speed, training load, match schedules, and access to equipment and coaching, to better tailor injury prevention strategies.

2.8 Kinematic variations and injury risk in female pace bowlers

Ball release speed, accuracy, and consistency are essential to pace bowlers' performance (Bartlett et al., 1996). Several studies have analysed the relationship between ball release speed and kinematics in male cricket players (Middleton et al., 2016; Worthington et al., 2013a; Wormgoor et al., 2010; Portus et al., 2004). Male pace bowlers had faster run-up speeds and maintained a straighter, non-dominant knee during the front foot contact phase. Male pace bowlers also demonstrated increased upper trunk flexion and delayed shoulder circumduction from front foot contact to ball release (Worthington et al., 2013a). This kinematic variable suggests that the best strategy for male pace bowlers to maintain faster ball release speeds is to initiate linear momentum during the run-up and convert it to angular momentum during the delivery phase. During the bowling action, the pace bowler will use the front leg to terminate the body's momentum while accelerating the body's top half to direct the ball delivery in line with the aimed target (Worthington et al., 2013a). Male bowlers' strategies to generate high ball release speed might differ from females.

The repetitive, rapid, and unorthodox action of pace bowlers increases the risk of injury compared to other player roles, such as batting and spin bowling (Portus et al., 2004; Dennis et al., 2003; Foster et al., 1989). There is a gap in research on the factors influencing injury and the performance of female pace bowlers. Stuelcken et al. (2008a) have shed some light on female pace bowling and found relevant musculoskeletal and biomechanical factors associated with injury in female pace bowlers. A recent study by Felton et al. (2019) reported that female pace bowlers had

reduced run-up speeds than male pace bowlers, with females having decreased linear momentum during their bowling action. Furthermore, during the transition from back to front foot contact, the male pace bowling action is optimised to maintain the linear momentum gained during the run-up, a benefit enhanced by higher upper body muscle mass that contributes to quicker deliveries and an advantage that females typically lack

Felton et al. (2019) also observed kinematic disparities between front-foot contact and ball release speed. Unlike the male pace bowlers, the female pace bowlers' angular momentum was inadequate to create faster ball release speeds. Alternatively, female bowlers adopted a throwing technique by enabling the pelvis and trunk rotator muscles to increase ball release speed. (Stuelcken et al., 2010a) discovered that elite female pace bowlers with low back pain have increased lumbar lateral flexion during the delivery stride (back to front foot contact). (Stuelcken et al., 2010a) also found that female pace bowlers were equally prone to lower back pain than males.

Although there is a lack of research on female cricket, studies in baseball have compared kinematic variables between male and female athletes. Chu et al. (2009) and Azuma et al. (2021) found that while female pitchers exhibit some similarities with their male counterparts, they also display distinct biomechanical differences. These include a shorter stride, less separation between the pelvis and torso, lower peak angular velocities, greater pelvic and thoracic rotation, and different tilt angles, all likely affecting their overall pitching mechanics and performance. While these findings are

specific to baseball, the similarities between the two sports suggest similar patterns may be observed in cricket. Further research is needed to describe kinematic variations between male and female fast bowlers effectively.

2.9 Conclusion

In conclusion, the increasing popularity and participation in women's cricket over the past decade and greater investments and enhanced SSSM support mark a critical period for the sport's development. Although significant progress has been made, there remains a need for more comprehensive research, particularly at sub-elite levels, to better understand the unique injury profiles, biomechanics, and physical preparation required for female cricketers. Given the anatomical differences between males and females, these variations likely result in distinct biomechanics and kinematics, which may influence injury risk factors and incidence rates in female players. Therefore, it is essential to study injury rates, profiles, and biomechanics specifically for female cricketers to inform targeted, evidence-based SSSM practices. Focusing on these unique challenges, especially for female pace bowlers, will help minimise injury risks and enhance performance, contributing to women's cricket's continued growth and success.

CHAPTER 3. APPLIED SPORTS SCIENCE AND SPORTS MEDICINE FOR FEMALE CRICKET PLAYERS

The aims and objectives of this chapter are presented **in Ch. 1, pg. 4.**

This chapter is presented as a manuscript of an article that will be submitted for peer-review in Sports Medicine.

PAPER 1

Applied Sports Science and Sports Medicine for Female Cricket Players: Systematic Scoping Review

Jolandi Jacobs, Benita Olivier, Corlia Brandt, Nico Grobler, Anna Saw

Abstract

Introduction: Women's cricket is vastly growing in popularity and participation. The development of women's cricket aligns with the emergence of scholarly literature on applied sports science and medicine.

Objectives: The primary aim was to search the available research on applied SSSM for female cricket players and to map the available evidence. The second aim was to identify research gaps in SSSM for female cricket players and prioritise future research strategies.

Inclusion criteria: The review included studies involving female cricket players of all ages and levels of participation from all geographical locations related to SSSM.

Methods: The PRISMA Scoping Review Protocol and JBI scoping review methodology were used for this review. This review included studies from the earliest record to September 12, 2023. The databases searched included MEDLINE, SPORTDiscus, EBSCOhost, ProQuest Health, ScienceDirect, Medical Complete, and Scopus. Further searches included trial registers (Cochrane Central Register of Controlled Trials and ClincalTrials.gov) and grey literature databases (WorldCat, Grey Matters, Grey Literature, Google Scholar).

Results: The database search identified 12997 studies with an extra 104 added from citation tracking and other sources. This review included 158 studies that met the inclusion criteria. Eight SSSM themes were covered, including injury (n=46), performance n=45), psychology (n=36), health (n=14), physical characteristics (n=5), match characteristics (n=5), fatigue and recovery (n=2), and nutrition and hydration (n=2). Most studies were conducted at national levels, with most publications from

Australia, India, and the United Kingdom. Areas of no research include female health, i.e., menstrual cycle, relevant energy deficiency, breast health, and injury prevention strategies and need to be prioritised for future research.

Conclusion: Findings from this review will guide the application of SSSM for female cricket players by informing clinical applications, highlighting research gaps, and prioritising future research for female cricket players to provide evidence-based support for the professional development of women's cricket.

Applied Sports Science and Sports Medicine for Female Cricket Players: Systematic Scoping Review

Jolandi Jacobs, Benita Olivier, Corlia Brandt, Nico Grobler, Anna Saw

3.1 Introduction

Women have been playing cricket for more than 200 years. The popularity of women's cricket has evolved in recent years from casual participation to professional full-time contracts, with women competing at the highest level in international tournaments (Hickey et al., 2016; Healy, 2020; Nicholson, 2020). Women's cricket is currently played at junior, community, sub-elite and elite levels. Female cricket players have a unique role in a team, such as batting, bowling, wicketkeeping, fielding, or multiple roles (Warren et al., 2019; Jacobs et al., 2022). Each player role in cricket requires a specific combination of technical, physical, and psychological qualities (Vickery et al., 2018a).

The development of cricket players requires collaboration between sports science and sports medicine (SSSM) practitioners, coaches and other support staff. Optimising individual performance and reducing the risk of injury ultimately contribute to team success (Bhardwaj and Dwyer, 2022; Vickery et al., 2018a). To translate research into practice and direct future research, a scoping review is required to map the current evidence related to SSSM on female cricket players (Evans et al., 2015; Orchard et al., 2010). Two reviews related to SSSM themes were published in 2022 and 2018. A

systematic review by Jacobs et al. in 2022 investigated injury epidemiology in female cricket players, and a narrative review by Munro and Christie (2018) suggested research directions for women's cricket in 2018. The review by Jacobs et al. (2022) only investigates injury epidemiology, and the literature review by Munro and Christie (2018) only included nine articles and did not adhere to the rigorous methodology of a scoping review. Hence, there is an apparent research gap in pooling the available SSSM publications for female cricket players to guide clinical practice.

A search for reviews in the Cochrane Database of Systematic Reviews, MEDLINE, and PROSPERO revealed no ongoing or previous reviews related to the topic of this review. This review aimed to scope all existing literature (peer-reviewed and grey literature) available on SSSM to map the current evidence for female cricket players. Further, this review identified areas for future investigations for SSSM for female cricket players. The review may assist women's cricket stakeholders in applying SSSM and coaches with decision-making and could contribute to the overall development of the women's game (Hickey et al., 2016).

3.2 Methods

3.2.1 Design

The scoping review was conducted according to JBI scoping review methodology (Peters et al., 2020), the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist (Tricco et al.,

2018), as well as the recommended best practice guidelines for scoping reviews by Levac et al. (2010) (**Appendix D**).

3.2.2 Eligibility criteria

The review included all studies relevant to applied sports science and medicine in women's cricket, with a detailed list of inclusion and exclusion criteria featured in **Table 3-1.**

Table 3-1: Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
- Studies involving participants who are female cricket players at all levels of participation - Studies on topic areas of applied sports science and medicine as per the operational definition and topic areas described in **Table 3-2.** - All literature (peer review and grey literature) - All languages - Publication since inception to 12 September 2023 - All types of studies (e.g. case-control, cross-sectional, randomised controlled trials, quasi-experimental, retrospective/prospective cohort studies, case studies, editorial commentaries, and text or opinion papers) - Specific data for female(s) extracted from studies that include both male and female cricket players	- No sex mentioned - Results where female data were combined with males and cannot be extracted for females alone.

To determine themes for this review, a priori, previously applied SSSM reviews (Whitehead et al., 2021; Bullock et al., 2021; Heyward et al., 2021; Shephard, 1998; Johnston et al., 2018) were used to identify the keywords used and the topic areas or themes covered. Additionally, primary/original research was reviewed during initial searches, and keywords and topic areas in these articles were included. If, during the searches, themes related to the operational definitions of SSSM emerged beyond those mentioned in **Table 3-2**, they were integrated into the operational definition for this review.

Table 3-2: Operational definition and topic areas

	Applied Sports Science	Applied Sports Medicine
Operational definition	Study of physical activity, exercise, athletic performance, and sports-related phenomena. Sports science includes biomechanics, psychology, nutrition, and anatomy to understand human movement, optimize performance, and prevent injury (Thompson et al., 2013).	The medical speciality that prevents, diagnoses, treats, and rehabilitates sports-related injuries and illnesses. Sports medicine includes orthopaedics, rehabilitation, cardiology, physiology, and more to optimise athletes' health and performance (Liddle et al., 2021).
Topic areas	Aerobic fitness, balance, biomechanics, coaching, coordination, fatigue, match and training characteristics, training load/volume, nutrition, performance, psychology, recovery, skill acquisition, strength, and conditioning.	Concussion, drugs and doping, health, heat stress, illness, imaging, injury, mental health, physical characteristics, physiology, well-being, female health.

3.2.3 Search strategy

A three-step search strategy was directed to identify both published and unpublished primary studies, reviews, text and opinion papers (Peters et al., 2020). *Step 1.* To identify keywords to include in the search strategy of this review, an initial limited search of MEDLINE (PubMed) was conducted. *Step 2.* The text words found in the titles and abstracts of relevant articles and the index terms used to describe the articles were used to create a comprehensive search strategy for each of the databases. An example of the search strategy used in MEDLINE (PubMed) is shown in **Appendix E.** The terms for the search strategy were "cricket*" AND "women" OR "woman" OR "female*" OR "girl*" OR "lad*" NOT "Gryllidae" OR "crickets".

Databases were searched from women's cricket inception (earliest record available) till September 12, 2023 (**Appendix E**). MEDLINE (PubMed), SPORTDiscus (EBSCO), Physiotherapy Evidence Database (PEDro), MasterFILE Complete (EBSCO), CINAHL Ultimate (EBSCO), Health and Medical Complete (ProQuest), Scopus (Elsevier), and ScienceDirect (Elsevier) were systematically searched. The Cochrane Central Register of Controlled Trials (CENTRAL) and ClincalTrials.gov were also searched. For unpublished studies and grey literature, the databases WorldCat, Grey Matters, Grey Literature, and Google Scholar were searched. Theses and dissertations discovered while searching grey literature databases were included in the review. All languages were eligible for inclusion, however only English search terms were used. Two non-English studies were identified and translated using an

online translator tool, Google Translate (Google, California, USA), to be incorporated into the review. This review considered studies on women's cricket from any country, regardless of cultural or sub-cultural factors or geographical location. *Step 3.* Additional papers were screened for the reference lists of articles identified for full-text review.

3.2.4 Study selection

Following the search, all the information of the studies identified was gathered and imported into EndNote X9.3.3 (Clarivate Analytics, PA, USA). All duplicates were manually eliminated. Following a pilot test, titles and abstracts were evaluated by two independent reviewers and assessed against the review's inclusion/exclusion criteria. The full text for the identified studies was located, and their citation information was imported into Microsoft Excel (Microsoft 365, Microsoft Corporation, Washington, USA). Two independent reviewers (JJ and NG) thoroughly examined the full text of selected studies against the inclusion/exclusion criteria (**Table 3-2**). Any disagreements between the reviewers at each stage of the selection process were resolved through discussion or with a third reviewer's (BO) assistance. The search results were presented in a Preferred Reporting Items for Systematic Reviews and Meta-analyses for Scoping Reviews (PRISMA-ScR) (Tricco et al., 2018) flow diagram in the final scoping review.

3.2.5 Data charting

Two independent reviewers (JJ and NG) used Microsoft Excel to extract data from papers. While extracting data from each included paper, the data extraction tool was modified and revised as needed (**Appendix F**). Data charting was done by JJ and reviewed by NG. The data charting and reporting were similar to previous scoping reviews on applied SSSM (Whitehead et al., 2021; Bullock et al., 2021; Heyward et al., 2021; Shephard, 1998; Johnston et al., 2018). All the authors (JJ, NG, BO, CB, AS) reviewed the findings reported in this review.

3.2.6 Data analysis

The findings of this scoping review were presented numerically and thematically in a narrative summary or tabular forms. The results were presented and discussed as SSSM themes identified through the review process. The quality of studies included in this review was assessed using an adapted scale from Hawker et al. (2002). Studies were rated good (structured abstract, clear introduction and aims, comprehensive methods, comprehensive description of statistical analysis and accurate results, sufficient transferability and implications), fair (some background and research questions outlined, method appropriate and results described, some missing sampling data, data analysis explained, results mentioned but more explanation could be given, data not transferable to greater population) and poor (no aim or objectives, question whether method is appropriate, few sampling descriptive details, minimal or no details

on data analysis, poor explanation of findings, minimal transferability). The homogeneity and heterogeneity of study populations for each study were assessed. Studies investigating players from the same level of play were categorised as homogeneous, while players with varying levels of play were categorised as heterogeneous. Gaps in research and future research directions for SSSM for female cricket players were identified and tabulated. Tables and figures were provided wherever possible to aid comprehension of the findings.

3.3 Results and Discussion

3.3.1 Search and selection of studies

The database search identified 12997 studies, and an additional 104 records were identified from other methods. After the removal of duplicates and screening against the inclusion/exclusion criteria, 158 records with full-text were included in the review. **Figure 3-1** captures the study selection process in the PRISMA Flow diagram.

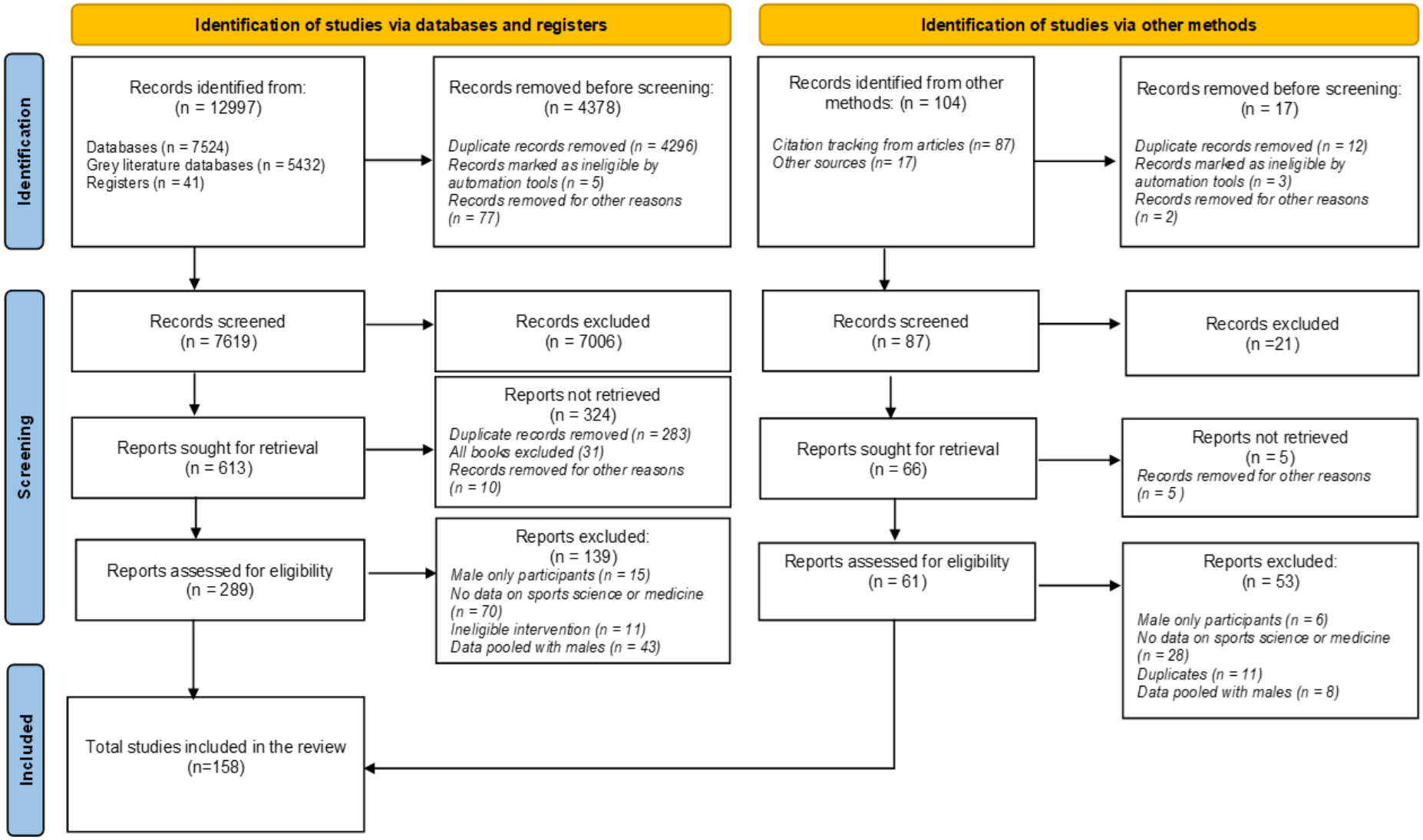


Figure 3-1: PRISMA flow diagram

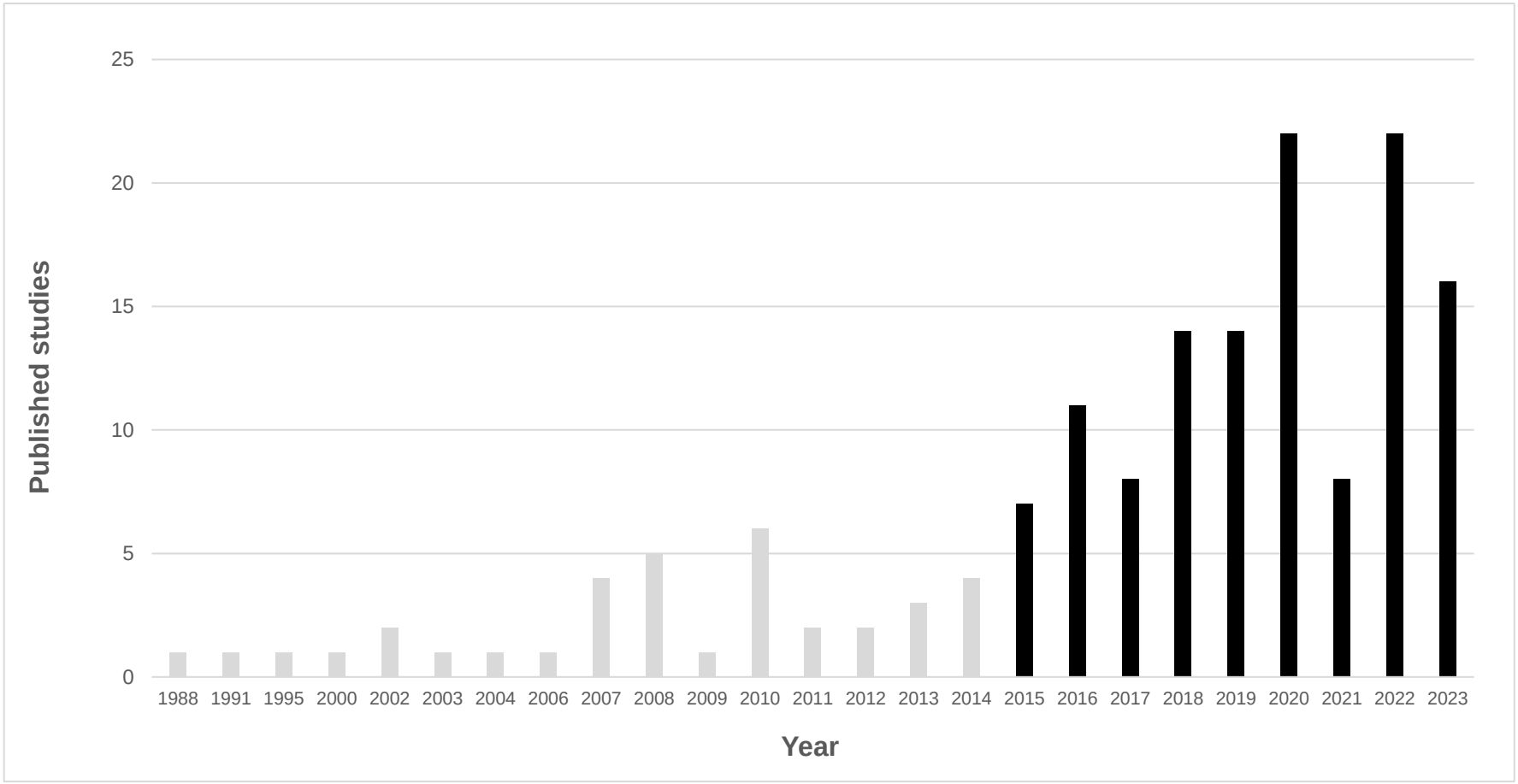
3.3.2 General characteristics of the studies

3.3.2.1 Sports science and medicine themes

Eight SSSM themes were addressed in the included studies: performance (physical strength capacity; biomechanics; training load/volume; skill acquisition; coordination/ proprioception; aerobic and anaerobic fitness) (n=45), injury (epidemiology; risk, management and prevention) (n=39), psychology (behaviour/cohesion, leadership/ communication, motivation/barriers, implementation, quality of life/mental health, mental skills, anxiety, body satisfaction, personality, imagery, support) (n=36), health (cardiovascular, bone, visual, neurocognitive, travel medicine) (n=21), physical characteristics (anthropometrics, physiology) (n=8), match characteristics (n=5), fatigue and recovery (n=2), and nutrition and hydration (n=2).

3.3.2.2 Publication year

Figure 3-2 demonstrates the publications for SSSM for female cricket per year from inception till September 12, 2023. Of the 158 studies on female cricket players, 80% (n=126) were published from 2015 to 2023. The increase in published studies in the last decade corresponds to the participation and investments in women's cricket (Hickey et al., 2016), advancements in sports science and technology (Garcia-Byrne et al., 2020), and institutional support (AIS, n.d.).



The black bars suggest the recent increase in publications in the last decade

Figure 3-2: Sports science and medicine publications for female cricket players per year (1988-2023)

3.3.2.3 Geography of studies

Figure 3-3 illustrates the geographic distribution of the studies conducted in 14 countries. Australia (n=50), India (n=47) and the United Kingdom (n=32) are the leading countries for publications on SSSM for female cricket players. Studies in Australia focused primarily on elite players at national and state levels (n=28) compared to India, which mainly explored SSSM at the club levels (n=18). Australia focused mainly on injury epidemiology (n=15), primarily facilitated by their longstanding database on elite players, which enables retrospective analyses (Orchard et al., 2023b). Other cricket nations should aim to develop a similar database for hosting SSSM data, which can be used for clinical analyses and research. Australia also published the most studies related to skill acquisition (n=6). The UK (n=6) and Australia (n=5) have contributed to 85% of the biomechanics studies on female cricket players. National Cricket Centres in the UK and Australia have new-age technology that they use to analyse the kinematics of their players to improve performance and reduce the risk of injury. India contributed 57% (n=20) of the psychology studies included in this review, aiding in the improvement of mental health and psychological strategies for female cricket players.

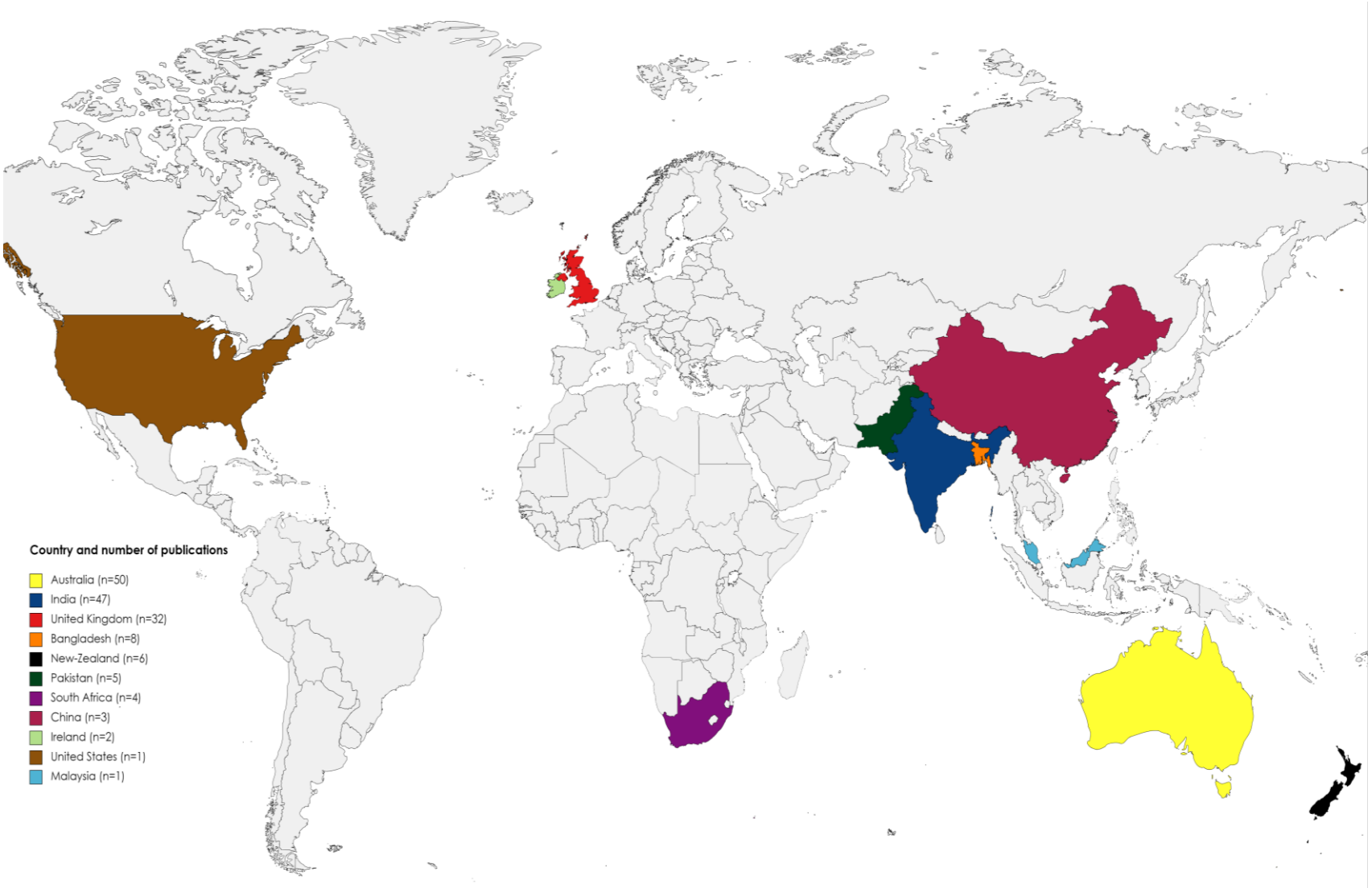


Figure 3-3: Sports science and medicine publications for female cricket players per country

3.3.2.4 Study designs and quality of data

Study designs included in this review were cross-sectional (n=87), retrospective (n=33), prospective cohort studies (n=23), intervention studies (n=5) and a randomised controlled trial (n=1). Quality assessment revealed that good (n=88), fair (n=52), and poor (n=18) quality studies were included in this review. Results from the studies were mainly conclusive (n=102), and some non-conclusive (n=56) results suggested further investigations on the topics. Most studies were conducted on females only (n=93), compared to other studies that included male and female cohorts (n=65). Grey literature studies included theses (n=5) and conference papers (n=7). The review predominantly included observational studies (n=144) and a small number of intervention studies (n=12). The large number of cross-sectional studies in this review suggests that researchers are using practical and cost-effective research methods to gain an overview of a cohort at a specific time point, reflecting the current challenges of limited investments and resources in women's cricket compared to the expansion and professionalism of women's cricket (Hickey et al., 2016). Future research in SSSM needs to conduct longitudinal studies to monitor SSSM themes over time and prioritise the design and implementation of more intervention studies. This approach will enable the observation of variables and yield higher-quality evidence-based findings for female cricket players.

3.3.2.5 Levels of play

Female cricket players in this review competed at national (n=44), club (n=20), provincial/state/domestic (n=13), district/division (n=5), community/recreational (n=2), premier (n=2) and junior levels (n=10). Several studies combined females participating at different levels of cricket in their cohorts (n=58), resulting in a high heterogeneity (46%) of cohort groups included in this review. Global variations in the professionalism of different levels of play are evident in this review. Collectively, the under-representation of lower levels of participation and the heterogeneity of cohorts in existing research limit the ability to draw conclusions and thus understand the SSSM themes specific to each participation level.

3.3.3 Sports science and sports medicine themes in female cricket players

A total of 158 studies were included in the review and covered eight SSSM themes. The summarises of the included articles are in **Ch. 3, Suppl. pg. 93-141.**

3.3.3.1 Fatigue and recovery

Two studies investigated fatigue and recovery in female cricket players (**Ch. 3, Suppl. Table 3-1**) (Gopinath, 2017; Mendhe, 2014). A fair-quality study on 60 Indian state players found that incorporating yogic practices may improve physical health, well-

being, and anxiety and aggression management during recovery (Gopinath, 2017). A fair-quality study on 60 junior cricket players in India found that players who performed three days of static stretching and muscle energy technique for the quadriceps muscle, performed similarly in the agility T-test, compared to a control group that did not stretch (Mendhe, 2014). Minimal findings on fatigue and recovery for female cricket players are evident, and future SSSM researchers should investigate this gap in the literature to guide practice.

3.3.3.2 Health

Twenty-one studies investigated health themes related to female cricket players (**Ch. 3, Suppl. Table 3-2**) (Menon et al., 2003; Bullock et al., 2020c; Evans et al., 2015; Saw et al., 2023; Perera et al., 2019b; Perera et al., 2019a-a; Saw et al., 2020; Hill et al., 2019; Orchard et al., 2020; Alway et al., 2023; Beech et al., 2019; Bullock et al., 2020a; Shah et al., 2020; Jones et al., 2018b; Barrett et al., 2017; Goh et al., 2021; James et al., 2021; Lallenec et al., 2021; O' Donovan et al., 2020; Lalor et al., 2021).

3.3.3.2.1 Cardiovascular health

Two studies reported findings on cardiovascular health in female cricket players (Menon et al., 2003; Orchard et al., 2020). A case report on a national player highlights a rare occurrence of a traumatic false aneurysm in a saphenous vein tributary, emphasising the importance of considering this diagnosis in post-traumatic swelling

cases (Menon et al., 2003). A study on 311 junior and state level female cricket players in Australia (Orchard et al., 2020) found a low prevalence of electrocardiogram (ECG) abnormalities when comparing this cohort to other heart characteristics and T-wave inversion in other female sports. Cricket players experience moderate cardiovascular demands when playing cricket, but there are no significant cardiac incidents or cardiac issues for female cricket players (Orchard et al., 2020). All cricket nations must adhere to cardiovascular guidelines for cardiovascular screening to identify possible health risk factors in current players (Orchard et al., 2020). Further research is required to compare the baseline ECG values of Australian cricket players across different geographic areas and ethnicities (Orchard et al., 2020). Future research areas could explore the impact of long-term cricket participation on cardiovascular health in female players, considering factors such as training and match intensity, duration of play, and potential cumulative effects.

3.3.3.2.2 Bone health

Ten studies investigated bone health among female cricket players related to bone adaptation, bone stress, and osteoarthritis (Alway et al., 2023; Bullock et al., 2019; Perera et al., 2019a-a; Beech et al., 2019; Bullock et al., 2020c; Saw et al., 2023; Evans et al., 2015; Shah et al., 2020; Jones et al., 2018b). Evidence of bone adaptation has been observed in elite pace bowlers, with significantly higher bone mineral density (BMD) across various skeletal sites, including total body, lumbar spine, and proximal femur (Alway et al., 2023). The asymmetrical loading of the pace bowling action may be attributed to higher BMD in the lumbar spine on the contralateral side

to the bowling arm and reduced medial tibial cartilage measurement of the front leg (Alway et al., 2023).

Bone stress has been observed in the lumbar spine, lower limb, and upper limb of elite female cricket players. Bone injuries in female cricket players occur not only due to non-contact and workload-related factors but also from contact with body parts such as the hand and wrist (Jacobs et al., 2022), affecting players at both elite and community levels. Training volume modification has been shown to allow recovery of a bone stress reaction in the distal humerus of a professional cricket player (Beech et al., 2019). Lumbar bone stress injury (LBSI) was only reported in two out of 279 players from 2010-2018 in Australia (Saw et al., 2023). Pace bowlers have the highest incidence of lumbar bone stress injuries similar to their male counterparts, however female bowlers presented with a higher proportion of bilateral and vertebral level L5 LBSI compared to males (Saw et al., 2023). Proactive strategies such as screening asymptomatic but at risk players or early investigation of symptomatic players with magnetic resonance imaging (MRI) may reduce the burden of bone stress in female cricket players (Saw et al., 2023). Lumbar spine injuries accounted for the most days missed (average 110.5 days/injury) in elite-level cricket in Australia (Perera et al., 2019a-a) and also the most days lost in elite UK cricket (Evans et al., 2015). Conservative management allowing time for the bone to repair and regain strength may reduce the risk of recurrent bone stress injuries (Saw et al., 2023), along with a holistic approach with the player's health and training load.

Joint pain is prevalent in current and former cricket players and is a long-term risk factor for developing osteoarthritis (OA) (Bullock et al., 2019). Osteoarthritis following hand injury has been observed in 2.3% of former and retired female national cricket players (Shah et al., 2020). Adequate hand protection (Shah et al., 2020) and conservative management of injury (Bullock et al., 2020c) may reduce the burden of osteoarthritis. Further research on retired female cricket players may reveal whether osteoarthritis of other body regions is associated with playing cricket. Further research is also needed to understand the inter-relation of many factors which may influence bone health of female cricket players over their career.

3.3.3.2.3 Visual health

One study investigated the importance of optimal corrected vision for national female cricket players in the UK (Barrett et al., 2017). Researchers reported that no players were colour-deficient, stereo acuity was better in adolescents, and no visual acuity disparities were observed among the subgroups (Barrett et al., 2017). Visual health affects hitting accuracy, fielding precision, and gaze tracking patterns, emphasising the need for comprehensive visual skills training to improve batting and fielding (Fogt, 2023). Limited research has been conducted on visual health in women's cricket, indicating a need for future research.

3.3.3.2.4 Neurocognitive health

Eight studies investigated neurocognitive health in female cricket players in relation to assessing for signs of concussion (Goh et al., 2021; Saw et al., 2020; James et al., 2021; Lallenec et al., 2021; Eunson et al., 2023; Perera et al., 2019b; Hill et al., 2019; Orchard et al., 2023b). Between 2015 and 2017, elite batters in Australia experienced an incidence rate of 3.7 head impacts (2.0 concussions) per 1000 player days (Hill et al., 2019). Head impacts were the most common cause for hospitalisation of cricket players in Victoria, Australia from 2002-2014 (Perera et al., 2019b). Injury incidence to the head and neck is high for female cricket players at a community level (Walter et al., 2022b). Applied SSSM practitioners can use video analysis to identify head impacts and review situational factors contributing to concussions in cricket (Saw et al., 2020). Video footage can present evidence of the location of head impact and the magnitude of the deflection of the ball from the helmet that could aid in the diagnosis and management of concussion (Saw et al., 2020).

Neurocognitive testing using a computerised assessment tool for sport (CogSport) has demonstrated that female players who have been playing a match for a median of 5.5 hours perform similarly on detection and identification tasks, but less accurately on one card learning and one back task compared to their rested baseline (Lallenec et al., 2021). Players who sustain a concussion perform worse than their baseline on three out of the four tasks (Lallenec et al., 2021; James et al., 2021). For concussed females, the sport concussion assessment tool (SCAT) scores indicated a relatively quick recovery, with an average of 3 days for symptoms to clear, eight days for a

complete graded return to play, and individual-specific timelines for resuming aerobic, resistance, and cricket-specific activities (Lallenec et al., 2021). CogSport accurately identifies concussed elite cricket players, suggesting its value in diagnosing head injuries, and clinicians can confidently interpret results, emphasising the importance of neurocognitive testing in the initial evaluation of head impact. Baseline scores from SCAT and CogSport can guide clinical management, and future research should explore shortened tests for time-sensitive situations without compromising the accuracy of the diagnosis.

3.3.3.3 Travel medicine

Two studies investigated travel medicine for international cricket players (O' Donovan et al., 2020; Lalor et al., 2021). Lalor et al. (2021) investigated sleep and jet lag during international travel and found that higher in-flight sleep efficiency is associated with lower perceived fatigue. Players presented with more extended sleep periods during international tournaments with earlier bed/wake times than their habitual sleep patterns (Lalor et al., 2021). Stakeholders should aim to sync the flight close to the player's usual sleep times, improving the quality and duration of sleep during flights. Further, SSSM should aim to reduce evening events, early training sessions and optimal recovery, especially after matches (Lalor et al., 2021). O' Donovan et al. (2020) found within-sample variations in the gut microbiome of seven national female cricket players between baseline and post-travel samples during their trip to India. Considering potential microbiome changes during travel is crucial to decrease risk of

gut microbiome alterations such as the acquisition of antibiotic resistance genes (O' Donovan et al., 2020). Further research is needed to understand how travel impacts the health of female cricket players and what strategies can be employed to improve performance.

3.3.3.4 Injury

3.3.3.4.1 Epidemiology

Thirty-two studies investigated injury epidemiology in female cricket players (**Ch. 3, Suppl. Table 3-3**). The studies reported injuries at national, pathway and state (Brooks et al., 2020; Cowan, 2006; Olivier et al., 2023b; Scanlan, 2023; Warren et al., 2019; Inge et al., 2019; Eunson et al., 2023; King et al., 2019; Pritchard et al., 2022; Goggins et al., 2020b), club (Bipasha et al., 2018; Basketter, 2014), community (McLeod, 2020b; McLeod et al., 2023) and junior levels (Grimmer et al., 2000; Wang et al., 2019; Coetsee and Phillips, 2007).

Several studies reported no level of play (Antoun and Lee, 2008; Bristi, 2015) or a combination of levels (Cai et al., 2019; Fernando et al., 2018; Forward, 1988; Hill et al., 2019; Kodikara et al., 2020; Orchard et al., 2023b; Paul, 2013; Perera, 2016a; Perera et al., 2019b; Walter et al., 2021; Walter et al., 2022a; Walker et al., 2010) in their cohort, causing heterogeneity of the data and providing challenges when translating the findings to the general cohort. Injury statistics are derived from a range

of sources, including medical records (such as AMS), survey responses relying on recall, hospital records, and insurance records, the majority of which were not specifically collected for research purposes.

As for injury definitions, seven studies used the Cricket Consensus definitions (Bipasha et al., 2018; Goggins et al., 2020b; Olivier et al., 2023b; Orchard et al., 2023a; Perera et al., 2019a-a; Scanlan, 2023; Inge et al., 2019), four studies used other medical definitions (i.e., lumbar bone stress, concussion, OA) (Hill et al., 2019; Saw et al., 2022; Saw et al., 2023; Walker et al., 2010), four studies used no definitions (Grimmer et al., 2000; Paul, 2013; Perera et al., 2019b; Beerworth et al., 2022a) and six studies used their own injury definitions (Bristi, 2015; King et al., 2019; Kodikara et al., 2020; Basketter, 2014; Coetsee and Phillips, 2007; Stuelcken et al., 2008a). Two studies reported injuries according to IOC Consensus Statement (McLeod et al., 2023; Orchard et al., 2023b) and four studies used OSICS-10 for data capturing and reporting (Perera, 2016a; Perera et al., 2019a-a; Scanlan, 2023; Eunson et al., 2023). Future SSSM research should use the Cricket and IOC consensus statements for injury definitions and the OSICS-10 standards guidelines to improve the quality and homogeneity of research for female cricket players.

Hospital studies report severe incidents, such as fractures, needing emergency medical care (Perera et al., 2019b). Nine studies included hospital data or medical records (Antoun and Lee, 2008; Belliappa and Barton, 1991; Fernando et al., 2018; Forward, 1988; Kodikara et al., 2020; Lee, 2012; Perera et al., 2019b; Wang et al.,

2019; Walker et al., 2010). These injuries include fractures to the head, neck and face (Antoun and Lee, 2008; Kodikara et al., 2020; Lee, 2012) and hand injuries (Belliappa and Barton, 1991; Forward, 1988). From 2002 to 2014, 78.5% of the 668 hospital cases reported in Victoria, Australia, had a hospital stay of fewer than two days (Perera et al., 2019b). Four studies reported injury epidemiology using insurance data or compensation claims (King et al., 2019; McLeod, 2020b; Perera, 2016a; Walter et al., 2022a). Female cricket injuries in New Zealand for 2007-2017 found 208 moderate-to-serious injury claims, costing $1,645,786, with an average of $7470 per claim, and three serious injury claims, costing $1,643,382 (2019). Future SSSM research should focus on the severity of injuries among female cricket players to reduce hospitalisations and the cost of injury for female cricket players. The highest injury incidence occurred in females aged 14 and younger (Bristi, 2015; Grimmer et al., 2000). The age group 10-14 had the most hospitalisations in Victoria, Australia, from 2002-2014, and injury surveillance in New Zealand from 2000-2005 (Walker et al., 2010) and 2005-2016 (Walter et al., 2022a). A high incidence of cricket injuries was also reported between ages 15-19 (McLeod et al., 2023), and another study reported a high incidence between ages 20-24 (McLeod et al., 2023). Researchers and clinicians should be mindful of the high incidence of injuries between ages 10-14 and address risk factors for injury in this population.

Elite-level injury incidence in Australia from 2014-2016 was 424.7/10,000 hours (h) for all injuries and 79.3 for time-loss injuries (Perera et al., 2019a-a). Elite-level injury incidence in the UK from 2016-2017 was 2.1 time-loss injuries and 12.2 non-time-loss injuries per 100 matches (Warren et al., 2019). Medical illness was the most common

complaint of 83 female pathway cricket players during the 2015-2019 seasons in the UK (Goggins et al., 2020b). Bowlers and fielders experienced higher incidence of injuries compared to other player roles (Goggins et al., 2020b; Orchard et al., 2023b; Bipasha et al., 2018). Fielding injuries typically result from activities such as catching and diving (Warren et al., 2019; Evans et al., 2015). Body regions most frequently injured were the shoulder (Bipasha et al., 2018; Scanlan, 2023; Basketter, 2014), wrist/hand (Perera, 2016a; Perera et al., 2019a-a; Warren et al., 2019) and lower limb injuries (Cowan, 2006), such as thigh muscles (Orchard et al., 2023b; Warren et al., 2019; Evans et al., 2015), knee (Paul, 2013; Perera, 2016a; Scanlan, 2023), and ankle (Bipasha et al., 2018; Bristi, 2015; Olivier et al., 2023b; Orchard et al., 2023b). Wrist/hand injuries were high in severity, with 27 elite females sustaining 73 hand fractures from 2015-2018 in Australia (Brooks et al., 2020).

The high incidence of shoulder injuries observed in the UK was attributed to throwing (Warren et al., 2019; Evans et al., 2015). A study on elite Australian cricket players highlights the prevalence of rotator cuff shoulder pain and instability in cricket, particularly while fielding or wicketkeeping, significantly impacting player availability (Pritchard et al., 2022). Muscle injuries are the highest in a self-reported survey and Australia's national injury surveillance system from 2014-2016 (Perera et al., 2019b) and injury surveillance in New Zealand from 2015-2016 (Walter et al., 2022a). Among elite level cricket players in the UK from 2016 to 2017 and Bangladeshi cricket players in 2015, overuse injuries were more common than acute injuries (Bristi, 2015; Warren et al., 2019). The high incidence of joint-related pain in the knee, back and hand was common in female cricket players (Cai et al., 2019). Stakeholders in women's cricket

should prioritise the availability of SSSM at non-elite levels to reduce injury risk in this cohort. Applied SSSM practitioners should implement strategies to reduce shoulder, wrist, hand, fingers and lower limb injuries.

3.3.3.4.2 Risk, prevention, and management

Seven studies explored injury risk, management and prevention for female cricket players (**Ch. 3, Suppl. Table 3-4**) (Goggins et al., 2022; Hecimovich and Stomski, 2016; Sulaiman et al., 2022; Beerworth et al., 2022a; Stuelcken et al., 2008a; Stuelcken et al., 2008b; Murphy et al., 2020). Female cricket players with a shoulder IR:ER strength ratio greater than 1.00 are especially vulnerable to shoulder injuries (Murphy et al., 2020). Beerworth et al. (2022a) reported that 39% of national and pathway-level players experienced shoulder issues, predominantly in the dominant arm, impacting training, performance and pain during 2021-2022. Modifications were made to throwing (83%), gym activities (35%), bowling (31%), and diving (18%) due to shoulder injuries (Beerworth et al., 2022a). Applied SSSM practitioners should use shoulder injury prevention programs, periodisation and load monitoring for throwing activities, and self-reporting measures to identify shoulder issues early, especially in larger cohorts (Beerworth et al., 2022a). Throwing and diving restrictions should be applied for short- and long-term injury treatment to reduce shoulder injuries and keep the shoulder IR:ER strength ratio close to 1:1 (Murphy et al., 2020).

Female pace bowlers displayed an increased external rotation range of motion (ROM) in their bowling shoulders compared to the opposite side, emphasising the need for SSSM to implement targeted training and rehabilitation programs to reduce recurring shoulder injuries (Stuelcken et al., 2008b). Female pace bowlers with a history of low back pain demonstrated a significant difference in lumbar lateral flexion ROM on the dominant side and increased bilateral hip extension ROM (Stuelcken et al., 2010b). Another study found that players with lower back pain present with increased lumbar lordotic angle (Hecimovich and Stomski, 2016). Increasing lumbar lateral flexion ROM symmetry and decreasing excessive lumbar lordotic curve may reduce the risk of lower back injury. Future SSSM research should investigate the link between hip ROM and the risk of lower back injury in female cricket players (2008a). To reduce the risk of lumbar spine injuries, SSSM practitioners can monitor bowling biomechanics, load management, and back stability programs (Perera et al., 2019a-a).

A study of the 2005 World Cup found that top-performing teams spent more time on endurance training and maintained a balanced approach to anaerobic and strength training, leading to fewer injuries during the competition (Cowan, 2006). Sulaiman et al. (2022) found a relationship between hamstring flexibility and reduced injury risk, highlighting the importance of hamstring flexibility in injury prevention strategies. Evidence suggests that effective workload monitoring and physical preparation for match or tournament demands decreased the risk of gradual injuries (Perera et al., 2019a-a). The session rating of perceived exertion (sRPE) is an accurate tool for SSSM practitioners to identify injury risk factors (Garcia-Byrne et al., 2020). Goggins et al. (2022) found that algorithmic models, especially generalised linear mixed effect

models, were more accurate at identifying injury risk factors by using variables such as smoothed differential 7-day load, average broad jump scores, and 20 m speed, which better predicted injury risk compared to traditional methods with lower accuracy.

The introduction of regulations for helmet use for batters and wicketkeepers in countries such as Australia has reduced the risk of injury (Eunson et al., 2023). It is recommended that cricket governing bodies should implement helmet regulations as personal protective equipment (PPE) to reduce the severity and incidence of head impacts. Given the high injury rates and severity observed in younger players, advocating for the mandatory adoption of age and skill-appropriate personal protective equipment (PPE) is an effective measure to reduce injuries, specifically in females aged 10-14 years. Skills development in younger age groups could also reduce injury risks (Perera et al., 2019b; Bristi, 2015; Grimmer et al., 2000). Skills development and using PPE such as gloves will also reduce the high incidence of hand injuries in cricket players (Brooks et al., 2020). The prevalence of medical conditions and injuries observed among female cricket players presents a challenge for SSSM staff in maintaining player availability. It also serves as a significant area for continued research to inform clinical practice (Goggins et al., 2020b).

3.3.3.4.3 Match characteristics

Five studies investigated match characteristics for female cricket players at the national level (**Ch. 3, Suppl. Table 3-5**) (Bhardwaj and Dwyer, 2022; Gupta, 2022;

Jadhav and Raizada, 2020; Munro, 2019a; Nicholls et al., 2023). Bhardwaj and Dwyer (2022) found that batting performance characteristics, especially the speed at which the first three to five batters are dismissed, hold greater significance than bowling characteristics in T20 cricket. Gupta (2022) quantified female batting performances using the Principle Component Analysis framework in ODI matches and suggested these methods for cricket stakeholders to improve batting performance analysis. Jadhav and Raizada (2020) examined the competitive scores of four national women's cricket teams indicating that governing bodies should establish more domestic leagues to increase grassroots exposure and competition to meet the demanding international standards. Time-motion analyses by Munro (2019) revealed that ODI innings in women's cricket lasted 169 minutes (min) and each over around 2.45 min, while T20 bowling innings lasted 75.50 min and each over around 2.52 min. Scoring patterns varied, with ODIs averaging 41 runs and 1.38 wickets in the first power play, while T20s averaged 122 runs overall and 37 runs with 1.45 wickets during the power play (Munro, 2019b).

Nicholls et al. (2023) highlighted the importance of female cricket training programs in addressing specific bioenergetics for movement demands and simulating match situations, given the differences in time intervals and run contributions between spin and seam bowlers, power play and non-power play phases. Studies on match characteristics in elite players offer valuable insights for SSSM to guide goal setting and develop performance analysis systems. However, additional research is required to match characteristics at the state/provincial and club levels to support professional development for these players. Technology such as global positioning systems (GPS)

or video monitoring could assist SSSM practitioners in examining the relationship between match characteristics and player performance to improve training programs and aid strategic decision-making.

3.3.3.5 Nutrition and hydration

Two studies investigated nutrition and hydration for female cricket players (**Ch. 3, Suppl. Table 3-6**) (Sobana, 2016; Soo and Naughton, 2007). Female club cricket players exhibited higher sports nutrition knowledge than males, particularly in carbohydrates, lipids, vitamins, fluids, weight management, and eating disorders (Sobana, 2016). Female cricket players frequently reported skipping meals for weight loss, an unbalanced diet, and a low-carb diet (Sobana, 2016). Another study included in the injury SSSM theme reported an 18% prevalence of general eating disorders and 76% of players underweight among female cricket players in Bangladesh (Bristi, 2015). Sports science and medicine practitioners should prioritise ongoing nutrition education to enhance players' relationship with food and overall health and performance. Soo and Naughton (2007) investigated the hydration of elite Australian cricket players and found body-mass losses during most of the player's cricket innings (69%). However, some instances showed increased body mass (28%), emphasising the need to monitor body mass changes during matches to help players accurately determine their fluid needs. Applied SSSM practitioners should implement practical measures to educate and monitor players to address hydration-related performance and medical complications. Targeted nutritional guidelines are essential to improve

adherence to dietary practices and optimise health and performance for female cricket players.

3.3.3.6 Performance

Forty-five studies investigated the performance of female cricket players (**Ch. 3, Suppl. Table 3-7**).

3.3.3.6.1 Physical fitness

Sixteen studies investigated physical strength capacity in female cricket players (**Ch. 2, Suppl. Table 3-7**) (Chanda et al., 2018; Chaurasiya and Mehta, 2018a; Chaurasiya and Mehta, 2018b; Das and Bidua, 2019; Dibba and Ganapathi, 2023; Gayatri and Sarojini, 2022; Letter et al., 2022a; Raj and Sudheer, 2016; Singh, 2016b; Sunble et al., 2022; Letter et al., 2022b; Boby, 2023a; Reddu, 2016a; Thomas et al., 2017; Boby, 2023b; Boby and Badhan, 2022).

A study reported that elite female cricket players had positive performance and motor fitness correlations, particularly abdominal strength, speed, and cardiovascular endurance. Applied SSSM practitioners should implement training interventions to improve these motor skills to elevate match success (Boby, 2023a). Bangladesh

cricket players between 17 and 25 years old had superior locomotion, speed, agility, cardiovascular endurance, and muscular strength endurance compared to standard benchmarks, demonstrating a high level of overall physical fitness (Chanda et al., 2018). Female cricket players who engaged in simulation-based training reported higher levels of perceived exertion (Dibba and Ganapathi, 2023). Additionally, the players showed improvements in physical performance measures such as maximal aerobic capacity, anaerobic power, explosive leg strength, total distance covered in a cricket exercise simulation test, and reduced time for completing one round of the test, compared to the control group (Dibba and Ganapathi, 2023). Thomas et al. (2017) compared the effectiveness of countermovement jump (CMJ), isometric mid-thigh pull (IMTP), and dynamic strength index (DSI) in predicting muscle strength capacity for female cricket players found that DSI is not a reliable predictor, while CMJ and IMTP are more accurate.

A study of state-level cricket players found that high-performing players had better cardiovascular endurance, explosive leg power, speed, and agility than low-performing players (Boby, 2023b). A study found a significant age effect on all physical qualities in female pace bowlers without age and season interaction (Letter et al., 2022b). The IMTP absolute and relative peak force was lower in 18-year-olds, while the best and average run-of-3 performance improved from 18 to 30 years (Letter et al., 2022b). Age groups 18-22 had lower absolute and relative one repetition maximum (1RM) bench pull strength than older groups, but in-season strength increased significantly (Letter et al., 2022b). The physical qualities of pace bowlers improve with age due to training effects that gradually enhance ball release speed (Letter et al.,

2022b). A study of division-level female cricket players found significant differences in explosive leg strength between the two teams, possibly due to practice environment variations, but no significant difference in agility (Boby and Badhan, 2022).

Chaurasiya and Mehta (2018b) found that Swiss ball core stability training enhanced female cricket players' upper and lower body strength. Raj and Sudheer (2016) found that a 12-week upper body strength training program improves overall fitness and increases upper limb strength in female cricket players. Sunble et al. (2022) found that periodised resistance training significantly enhanced sprinting speed, agility, lower limb, and upper limb power in junior female cricket players. Das and Bidua (2019) recommended speed training for improved performance for female cricket players. After an eight-week intervention program, yoga and non-yogic plyometric training significantly improved speed and agility (Gayatri and Sarojini, 2022). State and intercollegiate female cricket players performed equally in agility tests and performed similarly to males at the same level (Reddu, 2016a).

A study compared physical profiles between bowlers and batters and found higher shoulder muscle strength in bowlers and higher grip strength among batters (Chaurasiya and Mehta, 2018a). Sports science and medicine practitioners should be aware of the physical strength differences among each player role in cricket, emphasising the importance of player-specific physical preparation strategies. A study comparing faster and slower pace bowlers found significant differences in an average run of three, the best run of three, IMTP peak force, 1RM bench pull, and IMTP peak

force (Letter et al., 2022a). Applied SSSM practitioners should improve lower body strength, anaerobic capacities, and upper body pulling strength as physical preparation guidelines for pace bowlers (Letter et al., 2022a).

3.3.3.6.2 Biomechanics

Fourteen studies investigated the biomechanics of female cricket players (**Ch. 3, Suppl. Table 3-7**) (Alway et al., 2022, Bailey et al., 2023, Felton et al., 2019, Hamilton-Hastings, 2011, Liu et al., 2010, Lyons et al., 2023, McErlain-Naylor et al., 2021, Savage and Portus, 2002, Stuelcken and Sinclair, 2009a, Stuelcken et al., 2010a, Stuelcken et al., 2010b, Wood, 2010, Felton et al., 2015, King and Yeadon, 2012). Twelve studies investigated bowling biomechanics, and two studies batting biomechanics (Alway et al., 2022; McErlain-Naylor et al., 2021). Alway et al. (2022) investigated power-hitting batting biomechanics found that the batter increased their carry distance and had higher vertical launch angles when facing spin bowlers. Batters facing spin bowlers displayed techniques such as significantly less top wrist radial deviation, more significant ulnar deviation, and more whole-body anterior displacement towards the bowler between stance and impact (Alway et al., 2022).

Applied SSSM practitioners should know and address these variations in technique for effective power training strategies for batters. McErlain-Naylor et al. (2021) found differences in batting biomechanics between males and females. Male batters presented superior in maximum bat speed, carry distance, pelvis-thorax transverse

plane separation, lead elbow extension, bat angle and rear elbow angle, while female batters exhibited superior lead elbow flexion during the downswing (McErlain-Naylor et al., 2021). Sports science and medicine practitioners should aim to support female power-hitting biomechanics by addressing various factors, including individual characteristics, equipment used, task nature, and players' training and coaching history (McErlain-Naylor et al., 2021).

Bailey et al. (2023) investigated female pace bowling biomechanics and found that maximum velocity during the delivery stride, peak resultant acceleration, run-up distance, and peak roll are strong predictors of ball release speed. Female pace bowlers exhibited slower ball release speeds than males, potentially attributing to their smaller stature and lower whole-body linear momentum during the run-up (Felton et al., 2019). Female bowlers adopted a throwing technique by modifying their whole-body angular momentum using large rotator muscles (Felton et al., 2019). Additional SSSM research is needed to investigate the impact of anthropometric and strength limitations on pace bowling. Hamilton-Hastings (2011) suggested that increased elbow flexion and extension and ball release height did not impact ball release speed in female pace bowlers. However, the maximum height and the vertical velocity of the non-bowling arm significantly influences ball release speed (Hamilton-Hastings, 2011). A case study on a national-level cricketer found good elbow extension angles from markers during bowling trials with high-speed video and suggests future comparisons with current International Cricket Council (ICC) protocols to address unconsidered issues (King and Yeadon, 2012).

Pace bowlers exhibited a shorter duration between landing and ball release compared to spin bowlers, emphasising the importance of speed in their approach (Liu et al., 2010). Elite bowlers demonstrated greater stability in both landing and body positions when contrasted with their lower-level counterparts (Liu et al., 2010). The study delved into critical technical deficiencies such as knee collapse, elbow bending, and faults in the front foot during ball release, offering valuable insights for clinical guidelines in cricket coaching and player development. Moreover, factors such as bowling shoulder angle, height, run-up speed, and arm length were identified as significant predictors of ball release speed (BRS), with shoulder angle alone accounting for an impressive 89% of the observed variance (Lyons et al., 2023).

Faster BRS was associated with higher run-up velocities, specific knee movements, and a distinct arm circumduction pattern, resembling male pace bowlers (Lyons et al., 2023). Coaches and relevant SSSM staff should be informed that female pace bowlers may employ a trunk rotation technique, providing crucial insights for physical preparation for this cohort. Stuelcken et al. (2010a) found that shoulder distraction forces peaks during the early stages of bowling follow-through, with the maximum force typically reached in the initial follow-through. Bowlers with a history of lower back pain (LBP) exhibited distinct postural characteristics, including increased lateral flexion and thoracic range of motion during the delivery stride (Stuelcken et al., 2010b). Additionally, findings suggested that a higher shoulder alignment angle at back foot contact could influence hip-shoulder separation and shoulder counter-rotation,

potentially reducing the risk of injury (Wood, 2010). Run-up speed, knee angle, and shoulder angle caused variations in ball release speed in female pace bowlers (Felton et al., 2015).

3.3.3.6.3 Training load/volume

Two studies investigated training load/volume in female cricket players (**Ch. 3, Suppl. Table 3-7**) (Garcia-Byrne et al., 2020; Hoyne et al., 2022). A study exploring the workloads of elite cricket players found increased distances covered in international matches compared to national and junior matches (Garcia-Byrne et al., 2020). Player loads were higher at international and national levels with longer duration of matches, but junior cricket players reported higher sRPE (Garcia-Byrne et al., 2020). Applied SSSM practitioners should be aware of the increased player load and demand at the national levels and the higher reporting of sRPE by junior players. Hoyne et al. (2022) investigated self-reported loads in state female cricket players and found that players report their throwing loads on the same day of training. However, most players had an error rate of over 10%, indicating that self-reported throwing loads may be an inaccurate method of reporting throwing loads (Hoyne et al., 2022). Quantifying training and match volume is a challenge in cricket given the different skills and training/match environments. Future research may investigate different methods to quantify training and match volumes, with and without technology, to suit different playing levels and resources.

3.3.3.6.4 Skill acquisition

Seven studies investigated skill acquisition for female cricket players (**Ch. 3, Suppl. Table 3-7**) (Connor et al., 2020; Freeston et al., 2007; Lascu et al., 2022b; Lascu et al., 2021; Lascu et al., 2022c; Liang et al., 2023; Morgan et al., 2023). Morgan et al. (2023) analysed the 'Daughters and Dads Cricket' program and found high fidelity, attendance, satisfaction, and retention rates, exceeding feasibility benchmarks for skills acquisition in Australian junior cricket players. The program showed medium-to-large effect size changes in girls' cricket skill proficiency outcomes, confirming preliminary efficacy and positive impacts on girls' enjoyment, intention to play, and long-term retention in cricket (Morgan et al., 2023). Skill acquisition programs like "Daughters and Dads Cricket" should be implemented by stakeholders to increase skill proficiency and participation for junior cricket players.

A study that investigated the skill development practices at the club level presented a representative learning design, but a lack of adaptation in training was evident (Lascu et al., 2022b). The rising professionalism in women's cricket and expanding career prospects for young players necessitate increased opportunities for talent development. Future SSSM research should examine the impact of different training designs or tools on skill development and performance. Coaches and players in women's cricket prioritise early learning opportunities, linear career paths, and talent programs for early specialisation (Lascu et al., 2021). Increased exposure time increases player skill development as training methods frequently change (Lascu et al., 2021). Applied SSSM practitioners must evaluate task design elements and skill

development in amateur cricket players to reduce the impact of insufficient investments and support at the grassroots level.

Batters and bowlers improved their skills by 7% to 49% when guided by moderate to extensively organised training sessions (Lascu et al., 2022a). The study presented a moderate to extensive representative learning design that effectively promotes skill development in amateur cricket players and a tool for stakeholders for education and training designs in women's cricket (Lascu et al., 2022a). A study found that younger left- and right-handed batters performed equally in competition. However, among older teams, left-handed batters outperformed right-handers in average batting aggregate, runs per game, and batting time. Young female batters who used a reverse stance (holding the bat at the distal end of the handle) presented with higher batting aggregate, time and batting average than batters with a normal stance (Connor et al., 2020).

Freeston et al. (2007) examined the throwing performances (velocity and accuracy) of elite and sub-elite cricket players and found differences between elite male and female players and found that elite under-19 females exhibited lower accuracy than males in the same category. Liang et al. (2023) found that reduced throwing performance (reaching the ball and throwing velocity) in female club and country cricket players compared to males. Males and females employed similar throwing strategies, but males were quicker to reach and throw the ball at higher speeds (Liang et al., 2023).

Additional research on SSSM is needed to comprehend the underlying technical and physical factors that improve throwing performance in female cricket players.

3.3.3.6.5 Coordination/proprioception

Two studies explored coordination in female cricket players (**Ch. 3, Suppl. Table 3-7**) (Paul, 2017; Reddu, 2016b). Paul (2017) examined hand-reaction time and hand-eye coordination in female cricket and handball players found that cricket players have slower auditory and hand-eye coordination than handball players but faster visual reaction time. Reddu (2016b) investigated the coordination between high- and low-performing male and female cricket players by exploring rhythmic coordination abilities and found a notable difference in rhythmic ability between male and female low-performing players. Future research may seek to further understand the role of coordination in female cricket performance and injury risk and investigate strategies to improve this ability across playing levels.

3.3.3.6.6 Aerobic and anaerobic fitness

Four studies investigated aerobic and anaerobic fitness in female cricket players (**Ch. 3, Suppl. Table 3-7**) (Pankajbhai and Shantilal, 2015; Raj and Sudheer, 2018; Sandhu and Singh, 2018; Boby and Badhan, 2023). Sandhu and Singh (2018) found significant differences in Yo-Yo Intermittent Recovery Test Level 1 (YYIRTL1) scores between female cricket players from Bangladesh and India. Boby and Badhan (2023) found

that bowlers performed better in the YYIRTL1 with total distance run and VO_2 max. Applied SSSM clinicians must implement tailored training programs for each player role to improve aerobic capacity for players with low running scores for the YYIRTL1. A 2-week core exercise training program significantly improved running speed in the 4x10 shuttle run and the agility T-test (Pankajbhai and Shantilal, 2015). Raj and Sudheer (2018) found that aerobic dance and yoga significantly improved club-level cricket players' explosive power, flexibility, and endurance.

3.3.3.7 Physical characteristics

Eight studies investigated the physical characteristics of female cricket players (**Ch. 3, Suppl. Table 3-8**).

3.3.3.7.1 Anthropometrics

Six studies investigated the anthropometrics of female cricket players (**Ch. 3, Suppl. Table 3-8**) (Koley and Kashyap, 2010b; Singh, 2016a; Stuelcken et al., 2007; Tahoor and Koley, 2019; Thenmozhi and Indira, 2019; Mandoli and Sharma, 2018). Koley and Kashyap (2010b) found differences in mass between inter-university female cricket players and a control group and suggested that anthropometrics should aid in player selection, talent identification, and training program development. Singh (2016a) found that longer leg length, upper arm length, and total arm length predict the performance of female players at the club level. Tahoor and Koley (2019) found differences in non-

dominant handgrip strength, upper arm circumference, and body fat percentage, indicating positive correlations between various anthropometric parameters in club cricket players.

An analysis of bio-motor variables in elite and non-elite female cricket players showed a significant difference in speed and agility, with elite players demonstrating superior performance (Thenmozhi and Indira, 2019). Stuelcken et al. (2007) investigated anthropometrics of national players found that male bowlers had higher length, breadth, and girth than female bowlers, who had a higher sum of seven skinfolds, greater endomorphic, and lower mesomorphic characteristics. Mandoli and Sharma (2018) found physiological and anthropometric differences between batters and bowlers, particularly in vital capacity, pulse rate, leg length, and body fat percentage in domestic cricket players. Body size and composition has non-modifiable and modifiable factors. Although greater height and limb length, non-modifiable factors, seem advantageous for fast bowling performance, SSSM staff should be cautious when applying this insight in practice, especially with developing players. Additionally, caution is recommended when exploring the impact of body composition on health and performance to prevent issues like disordered eating and energy deficiency.

3.3.3.7.2 Physiology

Two studies investigated the physiology of female cricket players (**Ch. 3, Suppl. Table 3-8**) (Dwivedi, 2022; Negi and Pritam, 2012). A study on junior cricket players found a

significant difference in forced vital capacity between qualified and non-qualified teams, suggesting that superior lung capacity may influence performance in high-level players (Dwivedi, 2022). A study conducted in India revealed that national-level cricket players presented with lower diastolic blood pressure, pulse rate, respiratory rate, and breath-holding capabilities than state-level cricket players (Negi and Pritam, 2012). There is limited research on the physiological characteristics of female cricket players, and how they differ with age, fitness and ethnicity. Future research may investigate this are further, along with strategies to improve these characteristics if relevant. Additionally, it is important to consider the specific demands of cricket, including the playing duration and its physiological implications, as these factors directly affect the physical preparation and performance of players.

3.3.3.8 Psychology

Thirty-six studies (n=36) investigated the psychology of female cricket players (**Ch. 3, Suppl. 1, Table 3-9**). The psychology studies covered the following topics: dynamics and leadership (Acharya and Subudhi, 2023; Chaturvedi et al., 2013; Andrews et al., 2022; Webster et al., 2017), performance psychology (Anshuman, 2014; Khan et al., 2017; Kakran and Gurjar, 2020; Kohli, 2015; Navaneethan and Soundara Rajan, 2009; Van Rens et al., 2021; Singh, 2017; Gill, 2018; Kumar, 2013; Gurjar and Kakran, 2020; Yadav, 2020), motivation and support (Rubab and Iqbal, 2022; Rubab and Iqbal, 2021; Slathia et al., 2015; Bull, 1995; Marlow, 2002; Fowlie et al., 2021), and mental health and psychosocial factors (Bullock et al., 2020a; Ely et al., 2023; Ahmad, 2016; Gamit,

2013; Kumar and Gill, 2019; Sandhu et al., 2017; Singh and Kaur, 2016; Bhalla, 2018; Russell, 2004; Sharma et al., 2014; Sailan et al., 2016; Singh and Kumar, 2023; Shweta and Deepak, 2015; Warmenhoven et al., 2020; Jahangir and Manzoor, 2019).

Studies were conducted at national (Acharya and Subudhi, 2023; Andrews et al., 2022; Bhalla, 2018; Bull, 1995; Chaturvedi et al., 2013; Ely et al., 2023; Gamit, 2013; Khan et al., 2017; Marlow, 2002; Sailan et al., 2016; Sharma et al., 2014; Shweta and Deepak, 2015), state (Ahmad, 2016; Singh and Kumar, 2023; Van Rens et al., 2021), district/division (Gill, 2018; Slathia et al., 2015), club (Anshuman, 2014; Gurjar and Kakran, 2020; Kumar, 2013; Kumar and Gill, 2019; Reddu, 2016b; Sandhu et al., 2017; Singh, 2017; Singh and Kaur, 2016; Yadav, 2020) and junior level (Fowlie et al., 2021; Kakran and Gurjar, 2020).

Eight studies combined the levels of play in their cohorts when reporting the findings (Bullock et al., 2020a; Jahangir and Manzoor, 2019; Navaneethan and Soundara Rajan, 2009; Rubab and Iqbal, 2022; Rubab and Iqbal, 2021; Russell, 2004; Warmenhoven et al., 2020; Webster et al., 2017).

3.3.3.8.1 Team dynamics and leadership

Four studies explored team dynamics and leadership in women's cricket (Acharya and Subudhi, 2023; Chaturvedi et al., 2013; Andrews et al., 2022; Webster et al., 2017). Cohesion within a team set-up is essential for team dynamics (Acharya and Subudhi,

2023). Chaturvedi et al. (2013) found no significant differences when comparing competitive behaviour in male and female national players. Andrews et al. (2022) found that the social leadership skills of the captain, along with effective leadership, playing styles, and trust, are prioritised by coaches and players and identified as indicators of team effectiveness. Applied SSSM practitioners need to understand team dynamics, recognise the unique characteristics of leaders, and promptly address conflicts within female teams (Webster et al., 2017).

3.3.3.8.2 Performance psychology

Eleven studies explored performance psychology (Anshuman, 2014; Khan et al., 2017; Kakran and Gurjar, 2020; Kohli, 2015; Navaneethan and Soundara Rajan, 2009; Van Rens et al., 2021; Singh, 2017; Gill, 2018; Kumar, 2013; Gurjar and Kakran, 2020; Yadav, 2020). There are different self-confidence and goal orientations from various state and national teams (Gurjar and Kakran, 2020; Navaneethan and Soundara Rajan, 2009; Singh, 2017). Females at district-level cricket have higher aggression scores than males (Kumar, 2013). Females presented different mental toughness scores at junior (Kakran and Gurjar, 2020) and club levels (Yadav, 2020) and lower scores than males (Khan et al., 2017). There is a need for targeted individual interventions, such as Pressure Inurement Training (PIT) (Van Rens et al., 2021), to address psychological aspects of performance and to bridge the gap between theoretical principles and practical implications (Navaneethan and Soundara Rajan, 2009). Stakeholders should acknowledge the psychosocial development in women's cricket, considering recent shifts in power dynamics, increased opportunities, and

notable advancements in skill development and play negotiation, impacting overall performance (Kohli, 2015).

3.3.3.8.3 Motivation and support

Six studies explored motivation and support for female cricket players (Rubab and Iqbal, 2022; Rubab and Iqbal, 2021; Slathia et al., 2015; Bull, 1995; Marlow, 2002; Fowlie et al., 2021). Rubab and Iqbal (2021) found a positive correlation between extrinsic and intrinsic motivation, emphasising the importance of motivation on sports performance. External rewards positively influence the intrinsic motivation of elite female cricket players, underlining the need for recognition, rewards, security and support (Rubab and Iqbal, 2022). Club-level cricket players exhibited sex-specific differences in motivation and goal orientation (Anshuman, 2014). When identifying the needs of players, SSSM staff must prioritise considering players' perspectives, including historical and experiential influences (Marlow, 2002). Junior cricket players face obstacles, such as limited exposure to female-only competitions and restricted career advancement opportunities, which could impact their motivation (Fowlie et al., 2021). To promote an inclusive culture for junior players, SSSM practitioners should actively encourage the development of friendships and a sense of community. Recommendations from a sports psychology consultancy program with ECB stress the importance of cultural immersion, cautious psychological testing, and open communication between players and staff (Bull, 1995).

3.3.3.8.4 Mental health and psychosocial factors

Fifteen studies explored mental health, well-being and social influences in female cricket players (Bullock et al., 2020a; Ely et al., 2023; Ahmad, 2016; Gamit, 2013; Kumar and Gill, 2019; Sandhu et al., 2017; Singh and Kaur, 2016; Bhalla, 2018; Russell, 2004; Sharma et al., 2014; Sailan et al., 2016; Singh and Kumar, 2023; Shweta and Deepak, 2015; Warmenhoven et al., 2020; Jahangir and Manzoor, 2019). Studies discuss the psychological profile of female cricket players (Sailan et al., 2016; Bhalla, 2018), personality traits (Sharma et al., 2014) and body satisfaction of female cricket players (Russell, 2004), revealing psychosocial pressures. Evidence suggests that cricket participation promotes physical well-being (Bullock et al., 2020a). However, females presented with adverse effects of bio-bubbles on mental health, increased depression and anxiety, compared to out of bubble, emphasising the need for careful preparation and monitoring of these players (Ely et al., 2023).

Studies found higher (Ahmad, 2016; Ely et al., 2023; Singh and Kaur, 2016) or similar (Gamit, 2013; Singh and Kumar, 2023) anxiety scores for females compared to males. Higher and lower-performing female players presented with similar anxiety scores (Kumar and Gill, 2019) but different motivation scores (Sandhu et al., 2017), and findings suggest a link between anxiety levels and achievement motivation. Applied SSSM practitioners need to recognise the impact of anxiety and mental health on player performance and prioritise mental preparation in addition to technical skills (Shweta and Deepak, 2015). Family members, especially fathers (Warmenhoven et al., 2020), mentors, and peers (Jahangir and Manzoor, 2019), provide significant

financial and emotional support for female cricket players. Mental health and wellbeing are influenced by internal and external factors, hence it is difficult to generalise findings from the literature to other cohorts. SSSM practitioners may consider implementing a psychological screen to understand the specific strengths and challenges of the cohort they are working with.

3.3.4 Gaps in literature and future recommendations

While research on applied SSSM for female cricket players has increased in recent years, this review found gaps in the available literature. **Table 3-3** outlines research priority themes and sub-themes in women's cricket, highlighting significant gaps in the current literature. Several areas, including menstrual health, breast health, pregnancy, pelvic floor health, postpartum, and biomechanics for spin bowlers, have no evidence available. Other topics, such as long-term health, neurocognitive health, travel medicine, visual health, coordination/proprioception, training load/volume, fatigue and recovery, and nutrition and hydration, have minimal evidence, with only a few studies identified in each area. This highlights a critical need for further research to fill these gaps and improve understanding in these key areas.

Despite conducting a thorough study selection process and searching multiple peer-reviewed and grey literature databases, we might have missed articles relevant to SSSM in women’s cricket. While offering a broad overview of existing literature, this scoping review on sports science and medicine for female cricket players has several

limitations. These reviews are comprehensive but not exhaustive, often missing older but still relevant sources due to their limited availability in databases and search engines. Furthermore, most of the research included may disproportionately reflect specific demographics, affecting the generalisability of the results for all female cricket players across different levels and regions. Unlike systematic reviews, scoping reviews do not formally assess the methodological quality of included studies or synthesise quantitative data, which means they cannot establish cause-and-effect relationships, and low-quality studies could influence the results reported in this review. Additionally, the wide-ranging nature of scoping reviews makes it challenging to control for confounding factors. Although efforts were made to report and appraise the evidence objectively, these inherent limitations must be acknowledged.

3.4 Conclusion

This scoping review presented 158 studies on applied SSSM for female cricket players, primarily including national players from Australia, India and the UK. Eight SSSM themes were covered, with most studies on injury, performance and psychology. Areas of no research include female health aspects, i.e. menstrual cycle, relevant energy deficiency and breast health, and long-term health of female cricket players. This scoping review mapped studies relevant to SSSM for female cricket players to summarise evidence-based findings to guide applied SSSM for female cricket players across a range of playing levels and geographical areas to support the advancement of women's cricket. The increasing body of evidence for SSSM is an exciting and promising trend to support the professionalism of women's cricket.

Table 3-3: Priority areas and rationale for future research directions in SSSM for female cricket players

Research priority themes	Sub-themes	Rationale for identifying the theme for future research
Health	Menstrual and gynaecological health*	No evidence available
	Relative energy deficiency	No evidence available
	Breast health*	No evidence available
	Long-term health	Minimal evidence available (only two studies found)
	Neurocognitive health	Minimal evidence available (only three studies found)
	Travel medicine	Minimal evidence available (only two studies found)
	Pregnancy*	No evidence available
	Pelvic floor health*	No evidence available
	Postpartum*	No evidence available
	Visual health	Minimal evidence available (only one study found)
Injury	Menstrual health and injury	No evidence available
	Return-to-play guidelines	No evidence available
Performance	Menstrual health and performance	No evidence available
	Coordination/proprioception	Minimal evidence available (only two studies found)
	Biomechanics for spin bowlers	No evidence available
	Training load/volume	Minimal evidence available (only two studies found)
Match characteristics	At sub-elite and non-elite levels	No evidence available
Skill acquisition	Physical and technical factors for throwing performance	No evidence available
Fatigue and recovery		Minimal evidence available (only two studies available)
Physical characteristics	Physiology	Minimal evidence available (only two studies found)
Nutrition and hydration		Minimal evidence available (only two studies found)

**Female athlete domains as part of IOC Consensus Statement (Isabel et al., 2023)*

3.5 Supplement to Paper 1

Supplementary Table 3-1. Study characteristics of fatigue and recovery studies included in the scoping review (n=2)

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Data quality, homogenous/ heterogenous sample	Key findings	Practical implication
Gopinath (2017)	India, State level (n=60)	The study aimed to determine the effects of yogic practices on selected physical, psychological and performance variables among state level cricket players. Year of study not reported.	Yogasanas, Pranayama, Combined (yogasanas and pranayama), and 'no training' were the experimental groups. Outcome measures included flexibility (sit and reach test), endurance (12 min run/walk), anxiety, aggression, and cricket skills (batting, bowling, and fielding).	Female only. Homogenous. Fair.	According to research, integrating Yogasanas and Pranayama can benefit state-level cricket players and improve overall health and well-being. Yogasanas and Pranayama can help manage and cope with anxiety and aggression.	State cricket players may benefit from yogasanas and pranayama to improve their health and cope with anxiety and aggression.
Mendhe (2014)	India, Junior level (n=60)	This study aims to assess the time performance of female high school cricket players in agility tasks, specifically in various stretching techniques. To compare the effects of no stretching, static stretching, and muscle energy technique (MET) of the quadriceps on agility after performing the agility T-test. 2021	Experimental groups were asked to perform stretching techniques (no stretch, static stretch & muscle energy technique for quadriceps) on three successive days & completed the agility T-test after the three stretching techniques were executed.	Female only. Homogenous. Fair.	Agility T-test times for the control group (no stretch), static stretch group, and muscle energy technique (MET) group were 16.93 seconds, 16.3 seconds, and 16.18 seconds, respectively. ANOVA testing showed no significant difference (F=2.8, p=0.05). However, T-test analysis showed a significant difference between the control group and the MET group (p=0.02), but no significant difference between the control group and the static stretch group (p=0.057) or between the static stretch and MET group (p=0.72).	There was no significant difference found in agility performance after three days of quadriceps muscle stretching using static stretching, muscle energy technique, or no stretching at all following an agility T-test.

Muscle energy technique (MET).

Supplementary Table 3-2. Study characteristics of health-related studies included in the scoping review (n=21)

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
Cardiovascular health (n=2)						
Menon et al. (2003)	UK, National level (n=1)	We describe a case of a traumatic false aneurysm of a saphenous vein tributary in which the patient, a cricketer, came in with swelling over the left medial malleolus. Year of study not reported.	Contrast MRI	Female only. Homogenous. Poor.	The history and examination suggested a traumatic venous aneurysm and careful MRI analysis showed a vein distal to the aneurysm. The condition was rare, making preoperative diagnosis difficult. Although rare, this is an essential diagnostic consideration when examining a posttraumatic swelling patient.	This case report presents a traumatic false aneurysm of a saphenous vein tributary-the cricketer patient presented with swelling over the left medial malleolus. Traumatic false aneurysms in this area are uncommon but should still be considered as a possible diagnosis for posttraumatic swelling.
Orchard et al. (2020)	Australia, National, state and junior level (n=311)	To report the compliance and results of an electrocardiogram (ECG) cardiac screening program in male and female elite Australian cricket players . 2019	Cardiac screening included a personal and family history, physical examination, and a resting 12-lead electrocardiogram (ECG). Screening was conducted by physicians in each state.	Male and female. Heterogenous. Good.	This study included 311 females with an average age of 20.0±4.8. The following cardiac screening variables were reported: heart rate (bpm) - 69, PR interval (ms) - 147 QRS, duration (ms) - 87, QTc (ms) - 416 QRS, axis (degrees) - 69.2. Only 2.9% of the females had an abnormal ECG. Females had significantly more TWI and a longer mean QTc compared to males.	Elite cricketers exhibited a low prevalence of ECG abnormalities and underwent limited follow-up testing. No significant cardiac incidents occurred, and no players were disqualified from participating in sports due to cardiac issues. Elite cricketers exhibit ECG characteristics that align with the athlete's heart. Left ventricular hypertrophy criteria are more prevalent in males, while T-wave inversion is more prevalent in females. These findings provide additional evidence to support the claim that cricket is a sport that places moderate demands on the cardiovascular system.
Bone health (n=10)						
Alway et al. (2023)	UK (England), National and pathway level (n=37)	Determine, in females, whether bone mineral density (BMD) differs significantly by cricket position and whether there is asymmetry in BMD between the ipsilateral and contralateral sides of the lumbar spine or asymmetry between the hips, within each position. 2022	DXA scans	Female only. Homogenous. Good.	Cricket players have significantly higher Z-scores in the total body, lumbar spine, and proximal femur (with mean Z-scores ranging from +1.4 to +3.3) than a similar-aged reference population. Among them, fast bowlers exhibit higher bone mineral density (BMD) on the opposite side of the lumbar spine compared to the same side (p = 0.001, 5.9–12.1%). However, no hip asymmetry was observed in any of the groups. All cricket players showed high BMD across all measured sites. The lumbar spine of fast bowlers had asymmetry, with higher BMD on the opposite side, particularly at the L4 vertebra. This may be due to uneven loading patterns during bowling.	This study provides insights into the structural changes experienced by different playing positions and how different training volumes impact the BMD.
Beech et al. (2019)	UK (England), National level (n=1)	We report a diagnosis of bone stress reaction secondary to tensile forces in the throwing upper limb of a cricket player and highlight how modifications	Medical screening, including MRI, blood tests, Bone density scan and (computed tomography) CT scan	Female only. Homogenous. Poor.	In this case, a professional cricketer experienced throwing arm pain due to bone stress reaction in the distal humerus, confirmed by MRI. Modifying the patient's training led to a complete recovery within 6 weeks. The positive response to modified training suggests a biomechanical cause for the pain.	Implementing adjusted training protocols resulted in full patient recovery of a bone stress reaction within six weeks.

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
		to how this presentation is managed can lead to improved outcomes. 2019				
Bullock et al. (2019)	UK, All levels (n=15)	To evaluate the relationship between persistent joint pain (upper extremity, lower extremity or no persistent joint pain), PA levels and health-related quality of life (HRQoL), in former cricketers. To compare these relationships in former elite and recreational cricketer subgroups. 2017	Cricket Health and Wellbeing Study questionnaire.	Male and female. Heterogenous. Good.	Five teen females participated in the study. 3 reported upper and 4 lower extremity persistent joint pain.	-
Bullock et al. (2020c)	UK, All levels (n=65)	This study investigated the relationship between playing sports while injured and health-related quality of life (HRQoL), osteoarthritis, and persistent joint pain and compared findings in elite and recreational cricketers. 2017	Cricket Health and Wellbeing Study Questionnaire.	Male and female. Heterogenous. Good.	65 females participated in this study. 26(3%) reported that they never played sport injured, while 36(5%) reported that the played sport injured. For the age group >30 years, 21(5%) never played a sport injured, compared to 27(2%) who played a sport injured.	The long-term impact of playing while injured on musculoskeletal health should be considered when advising athletes on their ability to compete following injury.
Evans et al. (2015)	UK (England), National and pathway level, sample size not indicated	To describe longitudinal injury rates, types, severity and mechanisms in an International Women's Cricket Team. 2009-2012	Team Physiotherapist and Medical Officer recorded injury data for the England Women's and England Women's Academy Teams.	Female only. Homogenous. Good.	There were 160 non-time-loss injuries and 74 time-loss injuries (2604 days). The most days lost were due to lower back, ankle, and shoulder injuries. The thigh had the most injuries. The most severe injuries (>100 days lost) were ankle lateral ligament sprains and lumbar stress fractures in bowlers. Most time-loss injuries occurred during fielding (half of which were sustained while diving). The most common non-time-loss diagnoses were lower back pain (14%), especially in fast bowlers, and throwing shoulder pain (11%).	-
Perera et al. (2019a-a)	Australia, National level (n=121)	Incidence, prevalence, nature, severity and mechanisms of injury in elite female cricketers over two seasons. 2014-2016	Injury data collected via Cricket Australia's Athlete Management System were analysed.	Female only. Homogenous. Good.	According to the report, out of 600 medical-attention injuries, 77.7% of players reported at least one injury. The majority of injuries (79.5%) were acute. About 20.2% of medical-attention injuries caused time loss, while 34.7% caused match-time loss. The report found that match injuries accounted for 424.7 per 10,000 hours for all injuries and 79.3 for time-loss injuries. Muscle injuries accounted for 31.8% of all injuries, while joint sprains accounted for	Lumbar spine bone stress injury results in the most missed time. To prevent this type of injury, focusing on improving bowling technique, managing workload, and participating in back stability programs is essential. Skills training can help prevent hand and wrist injuries. Players who are pace bowlers and all-rounders are at higher risk of injury, so it's necessary to understand these

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
					16.0%. Among time-loss injuries, the most common were wrist and hand (19.8%), lumbar spine (16.5%), and knee (14.9%). Interestingly, six players missed the most days due to lumber spine bone stress injuries, averaging 110.5 days per injury.	risks and manage workload, schedule matches, and train accordingly to reduce the risk of injury. Remember that most injuries happen gradually, so managing workload, physical preparedness, and tournament scheduling is essential to reduce the risk of injury.
Saw et al. (2022)	Australia, National and state level (n=279)	This study investigated active lesions involving the lower thoracic to upper lumbar vertebrae, collectively referred to as upper lumbar spine bone stress injury (upper LBSI), in elite cricketers. 2010-2018	Data were retrieved from Cricket Australia's online Athlete Management System (AMS). Data in the AMS were standardised by medical staff (doctors and/or physiotherapists) working with state/territory and national cricket teams.	Male and female. Homogenous. Good.	Upper LBSI were observed in 2 female players out of a cohort of 279 from 2010 to 2018.	-
Saw et al. (2023)	Australia, National and state level (n=337)	To describe the presentation and management of lumbar bone stress injuries (LBSI), recurrent LBSI, and lumbar non-united defects in elite Australian male and female cricket players. 2009-2022	Data were retrieved from Cricket Australia's online database (Fair Play AMS Pty Ltd).	Male and female. Homogenous. Good.	During the study period, 337 female cricket players were contracted (120 players per season). A total of 18 females were injured. Over the 13 seasons, the average incidence of LBSI was 1.9 per 100 players per season. Pace bowlers had the highest incidence. Male and female players had similar injury presentations, except female players, who had a higher proportion of bilateral LBSI (16%) and a higher proportion of LBSI at vertebral level L5 (53%). The injury presentations of pace and spin bowlers were comparable. Over the 13 seasons, the average occurrence of recurrent LBSI was 6 per season (0.4 per 100 players per season). Four players experienced recurring LBSI. During the study period, four non-united defects were discovered. The average age of the first defect found was 17.8 years).	Non-united defects also have a high time cost with associated subsequent lumbar spine issues. The findings of this study reinforce the importance of early detection and conservative management of LBSI, which MRI may support.
Shah et al. (2020)	UK, All levels (n=43)	The objective was to describe the relationship between hand injury, ipsilateral pain, and OA in cricketers. 2017	Cricket Health and Wellbeing Study Questionnaire.	Male and female. Heterogenous. Good	20 current and 23 former cricketers were included in this study. 3 reported hand injuries. 2.3% of females were diagnosed with hand OA.	This study suggests that using personal protective equipment might not be adequate to prevent hand injuries in cricketers. Instead, strategies focused on neuromuscular exercise, proprioception, and strength training could be more effective.
Jones et al. (2018b)	UK (England), National level (n=6)	This study aimed to determine if the fast-bowling action in cricket, during which the front leg	MRI scans (3D sagittal FIESTA) were collected for both knees after the	Male and female. Homogenous. Fair.	A difference more significant than the minimal clinical important difference of 6.6% was seen in the normalised lateral tibial compartment in the female (11.9%) and total (7.7%) samples; the positive difference suggests the higher	A clinically significant difference in the normalised medial tibial compartment suggests that the higher-loaded front leg has a smaller medial tibial measurement than the back leg.

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
		experiences about twice the loading of the back leg, causes a clinically significant difference in the normalized medial or lateral tibial cartilage volume of the higher loaded front versus the back leg. 2018	conclusion of the most recent season.		loaded front leg has a greater lateral tibial measurement than the back leg. A difference more significant than the MCID was also seen in the normalised medial tibial compartment in the female sample (7.8%); the negative difference suggests the higher loaded front leg has a lesser medial tibial measurement than the back leg. The female medial tibia compartment had a significantly smaller measurement in the higher-loaded front leg than the back leg.	
Visual health (n=1)						
Barrett et al. (2017)	UK (England), National level (n=16)	Understand the importance of optimally corrected vision for high-level participation in these sports and look for evidence for better-than-normal vision. 2015-2015	Distance vision measures were taken using a logMAR chart, and near vision was measured using an MNRead chart.	Male and female. Homogenous. Good.	None of the female cricketers in the study were found to have any colour deficiency, which is consistent with the lower prevalence of red/green deficiency expected in females compared to males. However, the results for all participants showed that distance visual acuity was around 1 line of letters worse than expected when compared to published data for young, optimally corrected, non-sporting adults. This deficit was found to be significant ($p < 0.001$) when adopting $\alpha = 0.01$. On the other hand, near visual acuity did not differ significantly between subgroups or relative to published norms for young adults ($p > 0.02$ for all comparisons). Interestingly, the study found that, on average, near stereo acuity was better than in young adults ($p < 0.001$; $p = 0.03$).	There was a lower prevalence of red/green deficiency in females than in males. Overall, the players exhibited a significant deficit in distance visual acuity, worse than expected for young, optimally corrected, non-sporting adults. However, near visual acuity remained comparable to norms for young adults, and on average, near stereoacuity was found to be better than in the general young adult population.
Neurocognitive health (n=6)						
Goh et al. (2021)	Australia, National level (n=47)	Determine intra-individual changes in CogSport performance in elite cricket players diagnosed with a concussion and differentiate this from changes which may be attributed to post-match with no head impact. 2015-2018	CogSport performance and concussion. Cricket Australia's online Athlete Management System (Fair Play AMS Pty Ltd).	Male and female. Heterogenous. Good.	Out of the 47 concussions recorded, 9 players who were around 24 years old had data from the CogSport test on the day of their injury. The median duration of match play for them was about 1.5 hours. Their median RPE was around 5. It was found that the players had completed the CogSport test around 4 times before their post-match concussion test. On the other hand, 38 players who were around 23 years old underwent post-match testing without any head impact. The median duration of match play for them was around 5.5 hours, and the median RPE was around 5. It was also found that the players had completed the CogSport test around 4 times before their post-match test. Interestingly, one player in this group had a previous concussion and was included in the retrospective study.	Based on the findings, clinicians can confidently interpret CogSport results without being influenced by participation in a cricket match. Slower neurocognitive performance can be an indication of concussion in elite cricket players. Therefore, it is valuable to conduct neurocognitive testing in the initial evaluation of athletes with head injuries.
Hill et al. (2019)	Australia, National and	The objective of this study was to report the incidence of both concussion and	Cricket Australia's online medical recording platform (the	Male and female. Heterogenous. Good.	Over the 2 seasons, 15 head impacts resulted in 8 concussions in women's matches (on 367 team days of play). The match incidence rate was 3.7 head impacts (2.0	-

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
	domestic level (n=204)	head impacts at the elite level in cricket over 2 consecutive seasons. 2015-2017	Athlete Management System) or completed as hard copies postimpact, concussion-specific neurological tests (SCAT3 and CogSport) of Cricket Australia players; and any additional formal or informal notification of a head impact to any of the 3 primary study authors		concussions) per 1000 player days in elite female cricket. Batters (male and female) sustained 75% of the head (helmet) impacts.	
James et al. (2021)	Australia, National and state level (n=36)	This study aimed to describe the CogSport findings associated with concussion in elite Australian cricket players and to evaluate the diagnostic ability of CogSport for this cohort. 2015-2019	CogSport Data base	Male and female. Heterogenous. Good.	18 females presented with a concussion. Their CogSport concussion scores were as follow, with interindividual change in brackets : Detection speed - 325ms (34) Detection accuracy - 99% (0) Identification speed -472ms (44) Identification accuracy - 98% (0) One Card Learning speed - 799ms (18) One Card Learning Accuracy - 71 % (-7) One Back speed -660ms (84) One Back accuracy - 97% (-2) Total no of symptoms - 8/24 (5) Total symptom severity - 14/120 (7)	Elite cricketers with slower neurocognitive performance may have a concussion. Athletes with head injuries benefit from neurocognitive testing. CogSport accurately identified concussed and non-concussed individuals. In four of eight CogSport tests, concussion patients perform worse than baseline in detection speed, identification speed, one back speed, and one back accuracy. Neurocognitive testing like CogSport helps diagnose elite cricketer concussions after head impact. An abbreviated CogSport test with two or three components may be helpful in time-sensitive situations without compromising diagnostic accuracy.
Lallenec et al. (2021)	Australia, National level (n=17)	This study aims to retrospectively review SCAT data from concussed and non-concussed elite cricket athletes following a head impact to describe which clinical features on the day of injury are associated with concussion diagnosis. 2014-2019	Berlin Consensus Statement on Concussion in Sport and diagnosis was based upon practitioner review, review of video of head impact if available, neurocognitive testing using CogSport and SCAT.	Male and female. Heterogenous. Good.	It appears that eight females suffered from a concussion, with the average SCAT scores as follows: Total number of symptoms (6/22), symptom severity (8/132), percent of normal (70%), orientation (5/5), immediate memory (15/15), concentration (4/5), neurological screen (5/5), balance errors (1/5), and delayed recall (4/5). It took three days for them to become symptom-free, eight days to complete graded return to play, four days to commence aerobic activity, six days for resistance activity, and five days for cricket-specific activity.	This study's findings may help inform clinical management of head impacts in elite cricket.
Perera et al. (2019b)	Australia, All levels,	To present a comprehensive epidemiological profile of	A retrospective analysis of hospital-treatment data	Female only. Heterogenous. Good.	668 cases were treated in Victoria. These included 547 ED visits and 121 hospitalisations. In 78.5% of hospital cases, the stay was <2 days. Patients aged 10–14 were most	Young players (10-14 years) have fewer and more varied skills than adult players, which may explain their higher hospital rates. The high incidence of

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
	sample size not indicated.	hospital-treated injuries sustained by female cricketers in Victoria, Australia. 2002-2014	associated with cricket injuries sustained by women between 1 July 2002 and 30 June 2014, inclusive, was extracted from databases held by the Victorian Injury Surveillance Unit in Australia.		likely to visit the ED (19.9%) and be hospitalised (16.5%). Fractures caused 47.1% of hospital admissions but only 17.2% of ED visits. Dislocations, sprains, and strains caused 36.4% of ED visits. Head injuries were most common, followed by wrist and hand injuries.	head injuries suggests that players should use protective equipment and develop skills to reduce injury risk. This study's high joint-related injury rate indicates the need for women's cricket-specific neuromuscular injury prevention programs. Teenage and young adult female players had an increased fracture rate. Therefore, future studies should examine causative factors for fracture risk and type in this age group and implement and evaluate injury prevention strategies.
Saw et al. (2020)	Australia, National and state level (n=183)	The purpose of this study is to review video footage of concussive and non-concussive head impacts in elite Australian cricket players to identify situational factors associated with concussions. A secondary research outcome is information about situational factors related to head impact and concussion in cricket which may inform risk reduction strategies. 2014-2019	The concussion diagnosis was made by an experienced doctor specialising in sports medicine per the organisation's concussion protocol and consensus definition. Clinical assessment included a brief on-field assessment, off-field sports concussion assessment tool (SCAT), CogSport, and routine follow-up over subsequent days.	Male and female. Homogenous. Good.	183 females were included in this study. There were 11 head impacts during batting (~1 per 2,266 overs). There were 8 head impacts during fielding (~1 per 3,139 overs).	Impact on an unprotected head, the back of the head or helmet, or impact from a ball that stops or rebounds towards the source (except if it affects the front of the helmet) key situational factors are most consistent with concussion observed in this study. Video may be used to support the identification of head impacts and review situational factors in cricket. Improved impact attenuation of cricket helmets, particularly at the back, may reduce the risk of concussion.
Travel medicine (n=2)						
Lalor et al. (2021)	Australia, National level (n=11)	To determine the impact of the quality and quantity of sleep during an international flight on subsequent objective sleep characteristics, training and match-day load, self-reported well-being, and perceptions of jet lag of elite female cricketers during an International Cricket Council Women's T20 World Cup. 2021	Validated wrist-worn activity monitors were used to measure sleep (Actical; Philips Respironics Inc, Bend, OR)	Female only. Homogenous. Good.	In-flight sleep bouts' mean duration and efficiency were 4.72 hours and 87.45%, respectively. Aggregated in-flight sleep duration was 14.64 + 3.56 hours. Players with higher in-flight sleep efficiency reported higher ratings for fatigue (i.e., lower perceived fatigue) during the tournament period. Tournament sleep duration was longer, and bed and wake times were earlier than habitual. Sleep duration was shorter following matches than other nights during the tournament.	Efforts to mitigate the effects of air travel should prioritise improving the quality and duration of sleep during the flight, which may involve selecting a suitable cabin class. Scheduling flights close to or after one's usual bedtime can improve sleep quality during travel. Reducing wake bouts may enhance sleep quality, decrease self-reported stress, and alleviate soreness in elite female cricketers. To optimise sleep duration, it is advisable to implement scheduling strategies such as minimising evening commitments and avoiding unnecessarily early training sessions, especially after matches.

(O' Donovan et al., 2020)	Ireland, National level (n=7)	The possibility of gut microbiome-mediated negative impacts arising from travel, and consequences for peak performance, would be of particular concern for elite athletes. 2016	Omnigene-Gut collection kits (DNA Genotek Inc., Ottawa, Canada)	Male and female. Homogenous. Good.	Within the sample, alpha diversity was not significantly varied between baseline and final (i.e., post-India) time points. Subtle shifts were seen in individuals over time, with a mean decrease observed, though not significant ($p = 0.1–0.64$). Fluctuations in alpha diversity measures occurred in all cases, with more significant shifts observed within some individuals.	Travelling individuals should avoid those foods associated with the development of TD, including but not limited to raw and unpeeled produce, local water, uncooked meats, and unpasteurised dairy products. While individual fluctuations were identified, taxa associated with pre- and post-travel time points and experienced GI distress could be identified. Personal, pre-travel insults to the GI tract, such as reported distress or antibiotic usage, could influence the impact of travel on the gut microbiome.

Athlete management system (AMS), bone mineral density (BMD), electrocardiogram (ECG), emergency department (ED), health-related quality of life (HRQoL), low back stress injury (LBSI), magnetic resonance imaging (MRI), osteoarthritis (OA), p-value (p), QRS complex (QRS), corrected QT interval (QTc), Sport Concussion Assessment Tool (SCAT), United Kingdom (UK).

Supplementary Table 3-3. Study characteristics of injury epidemiology studies included in the scoping review (n=32)

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Injury definition	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
Antoun and Lee (2008)	New Zealand, level of play not indicated (n=1)	Investigate the prevalence, anatomic sites, and management of sports-related maxillofacial fractures in New Zealand. 1996-2006.	N/A	Medical/ hospital records.	Male and female. Heterogenous. Fair.	One female was admitted for a maxillofacial fracture playing cricket.	-
Belliappa and Barton (1991)	UK (England), level of play not indicated (n=3)	Review of hand injuries treated at the Nottingham General Hospital and the Queen's Medical Centre, Nottingham. 1975-1989.	N/A	Medical/ hospital records.	Male and female. Heterogenous. Fair.	Three females were hospitalised with hand injuries while playing cricket.	The pattern of hand injuries sustained in cricket is predictable. The little and ring fingers and thumbs are frequently involved, and joint injuries predominate.
Bipasha et al. (2018)	Bangladesh, Club and county level (n=51)	The present study was conducted to determine cricket injuries and their related pattern among injured female cricketers. 2017-2018	Injury definitions are in accordance with the International Cricket Consensus Statement(Orchard et al., 2005).	Face-to-face interviews by using an interviewer-administered structured questionnaire. The questionnaire was developed to obtain information on the respondents about the following factors: sociodemographic and physical characteristics, anatomical sites of injury, and related information.	Female only. Heterogenous. Poor.	Results indicated that bowlers are more prone to injury than any other player role. Shoulder, elbow, and ankle injuries accounted for the highest injury prevalence. Senior female cricketers were reported to be more likely to experience a recurrent injury than junior cricketers.	Practitioners should consider shoulder injury prevention programs, periodisation, the monitoring of throwing loads, and the use of a tool such as a self-report measure to identify shoulder problems early. Self-reporting measures can help triage large or remote groups of athletes.
Bristi (2015)	Bangladesh, Level of play not indicated (n=50)	To identify the prevalence of sports injuries among female athletes. Year of study not reported.	Own injury definitions: "Injury results from harmful contact between people and objects, substances or other things in their surroundings. Sports injuries result from acute trauma or repetitive stress associated with athletic activities. Sports injuries can affect bones or soft tissue (ligaments, muscles, tendons)."	Structured questionnaire developed by the researcher.	Female only. Heterogenous. Good.	The result of the study demonstrates that the peak age group was 14 or less than 14 years. The most common injury was ankle sprains 18%, and the prevalence of eating disorders 18%. Overuse injury accounted for 66%, and direct injury for 34%. Among the participants, 76% were below average weight. Among the participants, 98% regularly attend warm-up and cool-down activities. Players sought physiotherapy as frequently as medication or a combination of both.	Health education, regular physical activity, and physiotherapy exercises can prevent injury.

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Injury definition	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
Brooks et al. (2020)	Australia, National level (n=27)	This study aims to contribute to this gap in knowledge with a specific focus on hand fractures in elite Australian cricket players. 2015-2018	No injury definition was recorded. A physiotherapist or doctor diagnosed the hand injuries.	Data was retrieved from Cricket Australia's online Athlete Management System (Fair Play Pty Ltd). Data in the Athlete Management System is standardised by medical staff (Doctors and/or physiotherapists) working with state/ territory and national cricket teams.	Male and female. Homogenous. Good.	27 females reported 43 hand fractures over three years.	The results of this study inform clinical decision-making for non-surgical or surgical management and anticipated return to play times.. Further effort is needed to address risk reduction strategies, including gloves and skill proficiency.
Cai et al. (2019)	UK, All levels (n=24)	The purpose of the study was to describe the prevalence of joint pain and osteoarthritis in former cricketers. 2017	"Pain was defined in line with the National Health and Nutrition Examination Survey criteria for joint pain used previously to represent clinical signs of symptomatic OA."	Cricket Health and Wellbeing Study Questionnaire. The purpose of the CHWS was to evaluate and explain variation in 5 aspects of health and wellbeing in current and former cricketers (i. cricket-related injury; ii. pain and osteoarthritis; iii. general health and disease; iv. physical activity; v. resilience, quality of life and flourishing).	Male and female. Heterogenous. Good.	24 former female cricketers participated in this study with 3% reporting joint pain.	-
Cowan (2006)	South Africa, National level (n=112)	The purpose of this study was to determine the injury rate amongst international female cricketers, as well as anatomical areas which are more susceptible to injuries. A secondary aim was to evaluate how female cricketers prepare themselves for high-level competition. 2005	Own injury definitions: "An injury was defined as a pain which prevented a player from completing a match, a practice or a training session, or caused them to seek medical attention. Acute injury was defined as an injury that showed rapid onset with immediate pain and which had not been treated previously. A chronic injury was an injury which had been treated before and had a prolonged onset."	Injury and training questionnaire developed by researcher.	Female only. Homogenous. Good.	The injured players (mean age: 25.1 ± 1.10 years, height: 1.6 ± 0.02m, and weight: 61.9 ± 1.99 kg) yielded an injury rate of 0.48 injuries per player over the nine months. Most injuries were sustained during the World Cup (58%), most of which occurred in the second week of competition (12 out of 16 injuries). Muscle injuries accounted for most (43%) of the injuries. A large proportion of the injuries occurred in the lower limb, namely 59%. Upper limb and spinal injuries accounted for 26% and 15%, respectively.	This study suggests that higher anaerobic fitness leads to better performance and fewer injuries. Players should prioritise core strength training to prevent injuries. Lower limb injuries are prevalent in women's sports, including cricket. Players should seek advice on correcting biomechanical misalignments and scheduling sufficient lower limb conditioning. Coaches and trainers must ensure fielders and wicketkeepers are physically fit and proficient in cricket ball catching and retrieval techniques. Establishing a database for monitoring women's cricket injuries will aid medical teams and sports scientists in serving female cricketers better and advancing the game.

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Injury definition	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
Fernando et al. (2018)	Australia, All levels (n=290)	The study aimed to report the incidence of presentations to EDs in Victoria for sport- and active recreation-related injuries. 2012-2015	N/A	ED presentation data was extracted from the Victorian Emergency Minimum Dataset (VEMD), which records information (including level 1 injury surveillance data) from 38 Victorian public hospitals providing a 24-hour ED service.	Male and female. Heterogeneity. Good.	290 females were admitted to EDs in Victoria as a result of playing indoor/outdoor cricket	-
Forrester (2021)	United States, All levels (n=21)	This study aimed to describe cricket-related injuries reported to US emergency departments (EDs). 2000-2019	N/A	National Electronic Injury Surveillance System operated by the US Consumer Product Safety Commission.	Male and female. Heterogenous. Good.	21 females presented to United States emergency departments (2.5% of all cases in the surveillance system)	-
Forward (1988)	Australia, Indoor (national and domestic) (n=14)	The records of injuries that were sustained while playing indoor cricket were collected and reviewed. Year of study not reported.	N/A	Medical records of the Royal Perth Hospital	Male and female. Heterogenous. Poor.	Of the 14 women who presented with injuries, five women were off work for longer than one week, and all five were employed as secretaries; four of these five women had finger or thumb fractures. The fifth woman sustained a fractured radial head.	-
Goggins et al. (2020b)	England, Pathway junior and senior level (n=83)	To describe the primary injury and illness epidemiology of an international women's cricket development pathway in England and Wales to understand what may influence availability in this unique context where players are contracted part-time. 2015-2019	Injury definitions are in accordance with the International Cricket Consensus Statement (Orchard et al., 2016) "The term 'medical complaint' adopted by this study includes both injury and illness (excluding mental health) in line with the updated consensus statement."	Medical staff working with the international pathway defined and recorded any medical complaint (injury or illness) reported by the player that resulted in them being either available with or without necessary modified activity (non-time loss) or completely unavailable (time-loss) for match selection during the year, regardless of whether a match was scheduled.	Female only. Heterogenous. Good.	Around 8.4% of players were injured or ill, with 2.3% completely unavailable on any given day. The majority of medical issues occurred during training. Medical illness was the most common complaint, followed by hand injuries. Most injuries were gradual. While fielding had the highest injury rate, 'other' activities (e.g., non-cricket) accounted for 78.3 injuries/100 players per year. The women's cricket international pathway may have a higher rate of medical illness than other cricket samples.	The high occurrence of medical illness and injuries arising from 'other' activities is challenging for the players and sports practitioners involved in the pathway. It could highlight an area for future investigation and prevention.
Grimmer et al. (2000)	Australia, Junior level (n=76)	To report the prevalence of recent adolescent recreational and sporting activities and	No injury definition was recorded.	Injury and participation questionnaire	Male and female. Heterogenous. Good.	The risk of injury (odds ratios) for females who played cricket in Grade 7 was 0.40, and Grade 10 was 0.12.	-

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Injury definition	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
		associated injury. 1997					
King et al. (2019)	New Zealand, National and domestic level, sample size not indicated.	Provide a retrospective analytical review on the moderate- to serious injury claims and related costs for five sporting codes (cricket, netball, rugby league, rugby union and football) in New Zealand. 2012-2016	Own injury definitions: "Any injury assessed and reported by a registered health practitioner because of sports participation."	Data base from the Accident Compensation Corporation (ACC)	Male and female. Heterogenous. Good.	Moderate-to-serious injury claims for female cricket were 208 claims with a total cost of $1 645 796 and an average of $7470 ($4801 to $10 138) per claim. Serious injury claims for female cricket were 3 claims with a total cost of $1 64 382 and an average of $27 231 ($11 618 to $56 080) per claim (prices are in NZD$).	Accurate sport exposure data are needed to enable injury risk calculations.
Kodikara et al. (2020)	Australia, All levels, sample size not indicated.	To present an epidemiological profile of hospital-treated head, neck and facial cricket injuries in Victoria, Australia. 2007-2017	Own injury definitions: An "injury" was defined as "any cricket injury that required treatment at the hospital."	Hospital records from a Victorian hospital	Male and female. Heterogenous. Good.	Female cricket had a total of 324 injuries. Ninety-five female injuries requiring treatment at the hospital were sustained during formal cricket. The highest injury incidence rate for female cricket was 0.4 per 1000 female participants.	This study gives stakeholders a foundation for developing head, neck, and facial injury prevention strategies to make cricket safe for all. Injury prevention strategies must include formal and informal cricket activities since almost half of the injuries occur outside organised cricket facilities.
Lee (2012)	New Zealand, Domestic level (n=1)	This study will examine a cohort of patients who presented with cricket-related facial fractures at a tertiary hospital. 1996-2006	N/A	Medical records from Christchurch Hospital.	Male and female. Heterogenous. Fair.	One female (16–30 age group) presented with a facial fracture (2.5% of all cases).	-
McLeod (2020a)	Australia, Community level, sample size not indicated.	To understand the profile of injuries in cricket-specific activities. Investigate injury severity and time lost to work due to cricket-related injury as a measure of injury burden for community players. 2007-2019	N/A	National Club Risk Protection Program insurance claims data.	Male and female. Heterogenous. Good.	The average age of female claimants was 27.9 (SD 12.0) years. The highest proportion of female claims occurred in the 20 to 24 age group (19.6%, 95% CI 14.2% - 26.5%). The number of female claims was consistently higher proportionally than males in the age groups from 5 to 9 up to 20 to 24 years old.	-

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Injury definition	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
McLeod et al. (2023)	New Zealand, Community level, sample size not indicated	This study aimed to quantify injury claims in organised community cricket in New Zealand over 10 years. 2008-2018	Injury recording aligned with the International Olympic Committee consensus statement (Bahr et al., 2020).	Insurance claims data from the Accident Compensation Corporation (ACC).	Male and female. Heterogenous. Good.	A total of 5430 claims (8.6%) were from females. The group aged 15–19 years was most represented. Overall, there was a significant increase in the injury claims recorded (1.5% over ten years, p = 0.04). For bowling injuries, the 10–14-years and 45–49-year age groups shared the most significant proportion of claims. When bowling, the lumbosacral area was the most commonly injured area (25.3%). For batting-related injury claims, the lumbosacral area was also the most frequently injured body area (13.4%). For fielding, the knee was the most common claim (16.3%). Hand injuries were the most common claims in wicketkeeping (33.8%).	Reconsideration of how load management for bowlers is enforced is recommended if lumbosacral injuries are to be reduced. Wicketkeepers have high numbers of finger injuries despite being allowed to wear protective equipment. Glove design and fit should be looked at for potential improvement. Reasons for the relatively high number of knee injuries in community-level players should be investigated.
Olivier et al. (2023b)	South Africa, National level (n=6)	This study describes the type, side (dominant or non-dominant), occurrence, impact, activity of onset, and severity of foot and ankle injuries in elite South African male and female cricketers. 2018-2021	Injury definitions are per the International Cricket Consensus Statement (Orchard et al., 2016).	Cricket South Africa's team physiotherapists or sports physicians recorded all injuries sustained by elite cricket players on the Cricket Clinic software.	Male and female. Homogeneous. Fair.	Six elite cricket female players sustained foot and ankle injuries.	Effective rehabilitation programmes may reduce the risk of re-injury. Ideally, these programmes need to be role specific.
Orchard et al. (2023b)	Australia, National and state level (n=959)	This study presents seven seasons of injury surveillance data for both elite Australian male and female cricket players, revealing injury statistics and allowing for comparison between sexes. 2015-2022	Injury definitions are per the International Cricket Consensus Statement (Orchard et al., 2016). Injury recording aligned with the International Olympic Committee consensus statement (Bahr et al., 2020).	Injury data was recorded in Cricket Australia's Athlete Management System database and combined with match data.	Male and female. Heterogenous. Good.	The study had 297 unique female players, totalling 959.0 female player seasons. Female players participated in 1323 matches, resulting in 14,382 player match days. There were 3580 injuries in females, of which 293 were match time-loss injuries. The most frequent activities for females were fielding (36%), bowling (18%), and batting (14%). The most common injuries for females were hamstring strains (3.1), quadriceps strains (2.4), concussion (2.3), and lower limb/foot/ankle stress fractures (2.0). Females had a higher injury prevalence for spin bowlers (7.5% versus 5.2%, P < 0.001). The most prevalent	Elite Australian male and female cricket players had different injury profiles over the seven seasons examined. Robust long-term injury surveillance enables injury profiles to be understood to direct further research and risk-reduction strategies.

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Injury definition	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
						injuries for females were lower limb/foot/ankle stress fractures (0.9%), and hamstring strains (0.5%).	
Paul (2013)	Bangladesh, All levels (n=57)	To identify common injuries among female cricket players and investigate the management of injury. Year of study not reported.	No injury definition was recorded.	Self-administered questionnaire.	Female only. Heterogenous. Fair.	Out of the 57 participants, the mean age was 19.14 (±3.41) years, and the age range was (13-28) years. The ankle, knee and shoulder were most frequently injured. Of all injured players, 19.3% took medication, 15.8% attended physiotherapy and 64.9% combined physiotherapy and medication.	Taking precautionary measures to prevent ankle, knee and shoulder injuries is essential. Physiotherapy is a commonly used and effective treatment option for these injuries.
Perera (2016a)	Australia, All levels, sample size not indicated	This study investigated the injuries that contributed to successful insurance claims in Australia. 2002-2013	Own injury definitions: "Incident causing harm to a player and resulting in a (Jardine Lloyd Thompson Group) JLT-Sport insurance pay-out." Injury recording is aligned with the Orchard Sports Injury Classification System (OSICS-10) (Rae and Orchard, 2007).	De-identified insurance claims were extracted from the JLT-Sport database.	Female only. Heterogeneity. Good.	Out of 108 insurance claims, 89 injuries occurred during competition (82.4%), leading to an insurance pay out; most were incurred during batting (52.5%). Claims related to fielding reflected 38% of female cricket claims. Knee (24.1%), upper distal extremities including hand, wrist, and fingers (19.4%), and teeth (14.8%).	-
Perera et al. (2017b)	Australia, All levels (n=98)	Present a comprehensive profile of self-reported worst injuries among female Australian cricketers. 2014-2015	No injury definition was recorded.	Injury Surveillance in Women's Cricket in Australia Survey was administered online using Survey Monkey.	Female only. Heterogenous. Good.	The mean age of the 164 survey respondents was 23.7 years, and 43.6% were all-rounders. 18% sustained ≥3 injuries. The IR was 798.6 injuries per 1,000 participants. Distal lower limb (23%) and head, neck and spine (22%) were the frequently injured anatomical locations. Muscle injuries were the highest. Injured players reported seeking treatment from physiotherapists (43%) and opted for self-treatment (29.2%), and 12.5% did not seek any treatment for their injury.	The relationship between untreated injuries and the perpetuation of gradual onset injuries is a cause for concern, as it may represent overuse injuries. It is essential to address injuries promptly to prevent further damage and potential long-term consequences.
Scanlan (2023)	Scotland, National level (n=14)	To describe the incidence, nature, anatomical location and mechanisms of new medical attention injuries sustained by Cricket Scotland Women's Twenty-20	Injury definitions are per the International Cricket Consensus Statement (Orchard et al., 2016). Injury recording is aligned with the Orchard Sports Injury Classification System	Injury data was collected prospectively by the team physiotherapist.	Female only. Homogenous. Good.	There were 14 new injuries, 9 during matches and 5 during training sessions. Soft tissue injuries were the most common (78.6%), and the knee (35.7%) and shoulder (28.6%) were the most frequently injured areas. Most injuries were non-contact (78.6%) or overuse injuries (78.6%). Bowlers had the highest injury	Players specialising as bowlers and the technical aspects related to optimal bowling biomechanics, deserve attention, as players specialising in this role sustained the highest number of injuries.

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Injury definition	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
		Team during the Women's Twenty-20 International Cricket Council World Cup. 2019	(OSICS-10) (Rae and Orchard, 2007).			incidence proportion, with 0.57. No time loss injuries were reported.	
Walter et al. (2022a)	New Zealand, All levels (n=9350)	To provide epidemiological data for cricket injuries in New Zealand. 2005-2016	Own injury definitions: "any injury (minor, moderate-to-Serious and serious injury) that had been assessed and reported by a registered health practitioner because of sports participation".	Data was obtained from the National Accident Compensation Corporation (ACC).	Male and female. Heterogenous. Good.	9350 females reported 1105915 injury claims from 2005-2016. The body region with the highest injuries was the head, hand and fingers, knee, ankle and shoulder. Most injuries were soft tissue injuries. Most injury cause were contact type. Females recorded the most injuries in the 10–14 years age group.	Cricket injury prevention programs should focus on preventing hand, finger, and head injuries in players aged 10-14. Cricket coaches must emphasize protective gear and proper technique to reduce contact injuries.
Wang et al. (2019)	China, Junior level, (n=3)	To investigate the age, gender, and aetiology differences of sports-related fractures in children and adolescents (6–18 years old). 2001-2010	N/A	A database of two tertiary hospitals in Chongqing, China, was reviewed.	Male and female. Heterogenous. Fair.	Three females were admitted for cricket-related fractures.	-
Warren et al. (2019)	UK, National and pathway level (n=90)	To describe the injury incidence and prevalence during two years of a professional women's T20 cricket tournament. 2016-2017	Injury definitions are per the International Cricket Consensus Statement (Orchard et al., 2016). Injury recording is aligned with Orchard Sports Injury Classification System (OSICS-10) (Rae and Orchard, 2007).	For each match day, the squad physiotherapists were required to record the injury status of each squad member, regardless of whether they were playing or not, on an Excel spreadsheet.	Female only. Homogenous. Good.	The shoulder (1.8 injuries per 100 match days), lower back (1.7 injuries per 100 match days), and knee (1.7 injuries per 100 match days) had the highest incidence. The hand (1.7%), head/face (0.8%), and thigh (0.6%) had the highest time-loss prevalence. Concussions were the cause of all head injuries. Catching-related injuries were the most common (2.5% prevalence), and throwing-related shoulder injuries were the most common (2.3 injuries per 100 match days). Gradual onset injuries were the most common (7.9 injuries per 100 match days).	Traumatic injuries, specifically concussion and finger injuries, cause the most time lost in women's T20 tournament cricket. Further work is needed to prevent gradual onset injuries, mainly throwing arm pain. As the women's game grows, a standardised injury surveillance system would play a key role in injury prevention.
Inge et al. (2019)	Australia, National and state level, sample size not indicated	This paper aims to directly compare female to male injury patterns over 4 years in Elite Australian Cricket. 2019	Injury definitions are per the International Cricket Consensus Statement (Orchard et al., 2016).	State and National Medical Officers and physios did data collection.	Male and female. Homogenous. Good.	Injury rates in females were 5.9 % over the four years. The incidence of mental health issues in female athletes was higher than in males, although this difference did not meet statistical significance. For all other injury categories, males exhibited higher rates.	-

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Injury definition	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
Basketter (2014)	UK (England), Club and county level (n=52)	This study aimed to determine the injuries sustained in women's cricket. A secondary aim was to discover the risk factors associated with the women's game and how they might affect injury rates. 2013-2014	Own injury definitions: "Injury was defined as a problem that caused a player to miss training or playing time."	A questionnaire was used to collect injuries sustained by players during the summer season.	Female only. Homogenous. Fair.	28 out of 52 female cricket players reported injuries; a total of 40 injuries were reported. Injuries according to player role: batters 14, pace bowlers 7, spin bowlers 3, and wicketkeepers 4. 35 time-loss injuries were reported: 16 (<7 days), 6 (8-30 days), 4 (31-90 days), 9 (>91 days) 5 no-time-loss injuries were reported. Shoulder (28%), lower back (15%), wrist and hand (10%), foot (8%), thigh (8%), knee (8%), forearm (3%), elbow (3%), trunk (3%), and neck (3%).	More should be done to monitor bowling levels during the season or set a national guideline for coaches to follow for players' maximum bowling exposure in practices and matches. Female players need county-level access to physiotherapists and conditioning staff to improve injury management.
Coetsee and Phillips (2007)	South Africa, Junior level (n=8)	Investigate the incidence of anterior knee pain, the effect of sports participation, age at onset of the condition, gender differences and other factors that could influence the condition among 11-17-year-old males and females. Year of study not reported.	Own injury definitions: "Pain on the anterior surface of the knee on the diagram, listed pain more than one month's duration, indicated the severity of pain as moderate to severe, and indicated that the pain had interfered with sport participation."	The questionnaire was developed by the researcher.	Male and female. Heterogenous. Fair.	6 out of 8 females participating in cricket presented with anterior knee pain.	-
Eunson et al. (2023)	Australia, National and state level (n=121)	The purpose of this study is to retrospectively review clinical data of traumatic head and neck injuries sustained during cricket participation for elite Australian male and female cricket players. 2010-2022	Injury recording aligned with Orchard Sports Injury Classification System (OSICS-10) (Rae and Orchard, 2007).	Data was extracted from Cricket Australia's Athlete Management System.	Male and female. Heterogenous. Good.	seventy-three traumatic injury events to the head and neck were recorded over the 12 seasons (mean age 23.2 ± 5.2 years). The average head and neck injury incidence was 5 per 100 players per season. The average incidence of injury events prior to the introduction of helmet regulations was 2.5, and from July 2016 onwards, it was 7.8. The average incidence of time-loss and more severe injury events before to the introduction of helmet regulations was 0.8, and from July 2016 onwards, it was 2.2.	The introduction of helmet regulations has been an effective risk-reduction strategy for batters and wicketkeepers. However, additional risk reduction may be offered by tightening these regulations. For instance, refining the industry standard and extending regulations at the governing body level. Ongoing player education and skill refinement also have a role.
Walker et al. (2010)	New Zealand, All levels, (n=70)	This paper describes injury (circumstances and type) experienced by sub-	Data was coded to three editions of the International Classification of Diseases 10th Revision, Australian	Cases were identified retrospectively from NZ's National Minimum Data Set of	Male and female. Heterogenous. Good.	Being struck by the ball was the most likely cause of female injury-62% of head injuries to females. Falls, overexertion and collision were frequently identified. Analysis of injury	This study is vital for manufacturers of PPE as it provides details of the effect of each agent and mechanism of injury on each age

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Injury definition	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
		populations at all levels of cricket and, where possible, the type of player protective equipment (PPE) used. 2000-2005	Modification (ICD-10-AM editions 1–3) and included all first admissions with an external cause of injury 'ecode'.	public and private hospital discharges and day patients.		patterns within selected age ranges showed that the largest group was aged 10–14. 75% of injuries were to the head and included a slightly higher proportion of females than the total series (20% vs. 15%).	group and region of the body. It may be time to consider promoting the compulsory use of PPE by those of younger ages who are playing at lower levels of cricket. The difference in injury patterns between children and adults also points to a need for different types of PPE at different skill/age levels.
Pritchard et al. (2022)	Australia, National and pathway level (n=109)	This study aimed to describe the incidence and nature of all shoulder injuries requiring any modification in elite and emerging female cricket players and the treatment and management of shoulder injuries in elite and emerging players. 2022	No injury definition was recorded.	All injuries to the shoulder complex which required any modification to training or match activity were included. Clinical consultation notes and activity data recorded at the time of injury.	Female only. Homogenous. Fair.	Most injuries occurred to the dominant shoulder (77%), during a match or cricket-specific skills training (81%), while fielding or wicket keeping (85%), and when catching/diving or falling (57%). The most common injuries were rotator cuff shoulder pain and shoulder instability. One in three injuries resulted in the player being unavailable to play or train, and two in three did not. Number of days to return to full unrestricted match play was 79 days. Essential short- and long-term modifications were throwing and diving restrictions.	This study provides insight into the specific shoulder injuries sustained by female cricket players. This includes non-time-loss injuries, which contribute to the considerable burden of players being unable to participate in cricket fully. Practitioners should consider strategies to reduce the burden of shoulder injuries, which would positively affect player health and team performance.

Accident Compensation Corporation (ACC), Cricket Health and Wellbeing Study (CHWS), eating disorder (ED), Orchard Sports Injury Classification System (OSICS-10), osteoarthritis (OA), personal protective equipment (PPE), United Kingdom (UK).

Supplementary Table 3-4. Study characteristics of injury risk, management and prevention studies included in the scoping review (n=7)

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
Beerworth et al. (2022a)	Australia, National and pathway level (n=259)	This study used player self-reports to understand past shoulder problems and quantify the burden of current shoulder problems throughout a cricket season. 2021-2022	The survey consisted of the Kerlan–Jobe Orthopaedic Clinic shoulder and elbow score and the Oslo Sport Trauma Research Centre overuse injury questionnaire.	Female only. Heterogenous. Poor.	102 (39%) players reported a shoulder problem at one or more time points during the season: 21% reported difficulties participating in training/ competition, 17% reported modified activities, 17% reported their performance was affected, and 36% reported shoulder pain. Of those who reported the affected side, 92% affected their dominant shoulder; of those who reported modified activities, 83% modified throwing, 35% gym, 31% bowling, and 18% diving.	-
Goggins et al. (2022)	England, Pathway junior and senior level (n=17)	The study aimed to conduct an exploratory analysis to investigate how algorithmic models may be able to identify important risk factors for injury in an international women's cricket development pathway in England and Wales, which may not otherwise have been apparent. More conventional data models were then used to assess the association between these risk factors and injury. 2018-2019	ECB medical staff working with the international pathway defined and recorded any injury using an Excel spreadsheet.	Female only. Heterogenous. Good.	The best-fitting generalised linear mixed effect model for predicting injury contained smoothed differential 7-day load ($P < 0.001$), average broad jump scores ($P < 0.001$) and 20 m speed ($P < 0.001$).	Evidence for a load measure involving session rating of perceived exertion, which was more predictive of injury than overs bowled. Advice for sports practitioners on selecting appropriate physical tests for injury risk screening and showcasing alternative use of algorithmic models for injury risk factor identification versus traditional injury prediction.
Hecimovich and Stomski (2016)	Australia, Junior level (n=26)	Determine the range of sagittal plane lumbar curvature and examine its relationship with a previous lower back injury in young junior-level cricket players with a view that this may be a risk factor for injury and, therefore, an accepted protocol may be developed for its monitoring. 2016	A standard flexible ruler (flexicurve) was used due to it being inexpensive with minimal equipment and no exposure to radiation.	Male and female. Homogenous. Good.	Twenty-six females were included in the study. Nine reported lower back pain. Players with previous lower back injury (PLBI) had significantly more significant degrees of lordosis. Females with PLBI = 45.41° and females with no PLBI = 30.31°.	The results indicate lumbar lordosis may be an issue worth examining in athletes who partake in sports with high levels of extension; however, as there is no accepted definition of lumbar postures, it is challenging to interpret measurement results accurately. Examination of athletes with a history of low back pain should include measurement of the lumbar lordotic angle.
Murphy et al. (2020)	Australia, Domestic level (n=115)	To examine the risk factors for dominant-side shoulder injury in elite female	A battery of pre-season tests was included within this study. Physical performance tests	Female only. Homogenous. Good.	Fourteen players developed dominant shoulder injuries (12%). Injuries were associated with shoulder IR:ER strength ratio (OR = 1.84, P =.01), rear foot hip abduction strength (OR =	In elite female cricketers, the dominant shoulder IR: ER strength ratio was linked to a dominant-side shoulder injury. Players who developed shoulder injuries had lower

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
		Australian cricketers. 2017-2018	included measures of fitness and horizontal pull force. MSS tests included measures of shoulder range of motion, shoulder strength, hip strength, scapula dyskinesis, hypermobility, and combined elevation.		0.973, P =.049), and back foot hip adduction: abduction strength ratio (OR = 1.44, P =.047). Only shoulder IR:ER strength ratio remained significant (P =.016), with a 79% increase in shoulder injury risk per 0.1 ratio. This study found that elite female cricketers with a shoulder IR:ER strength ratio >1.00 are most at risk for shoulder injury.	hip adduction: abduction strength ratio on the throwing stance leg, but this needs to be confirmed in a larger population. Elite female cricketers should reduce dominant-side shoulder injuries by keeping the shoulder IR: ER strength ratio close to 1:1 and increasing hip abduction strength.
Stuelcken et al. (2008a)	Australia, National level (n=26)	To determine the career history of low back pain (LBP) in current elite female cricket fast bowlers and then compare measures of lumbar spine and hip range of motion (ROM) and trunk extensor endurance between those bowlers with and without a history of LBP. Year of study not reported.	Data were collected using a self-administered questionnaire and medical records. Several lumbar spine and hip motion tests were collected using goniometry. The trunk extension was tested using a modification from the Sorensen Test.	Male and female. Homogenous. Good.	Fourteen female fast bowlers had a history of LBP. There was a significant difference in lumbar lateral flexion ROM to the bowling arm side between those female fast bowlers with and without a history of LBP. The female fast bowlers had significantly more bilateral hip extension ROM compared to the male fast bowlers.	-
Stuelcken et al. (2008b)	Australia, National level (n=26)	This study investigated the prevalence of shoulder pain and compared the strength and range of motion of female fast bowlers in Australia with and without shoulder pain. Year of study not reported.	Data on injuries, player demographics, cricket experience, and history of shoulder pain related to or aggravated by bowling or throwing were collected using a questionnaire.	Female only. Homogenous. Good.	There were significant bilateral differences in the external rotation range of motion for those bowlers without a history of shoulder pain ($p < 0.05$) and in the internal rotation range of motion for both the total cohort and those bowlers with a history of shoulder pain ($p < 0.05$). There was an association between concentric internal rotation torque for the bowling shoulder and years of fast bowling ($rs = 0.45$).	Female fast bowlers with no history of shoulder pain exhibited more external rotation range of motion in their bowling shoulders than their non-bowling shoulders. Practical shoulder training and rehabilitation programmes are required to deal with the recurrent shoulder pain problem in women's cricket.
Sulaiman et al. (2022)	India, Club level (n=25)	The study aims to compare the hamstring muscle length of male and female cricket players associated with low back pain. 2022	Hamstring flexibility was measured using the active knee extension test. A lag of 20 degrees is considered normal from full extension. Anything less than 20 degrees was considered as hamstring tightness.	Male and female. Heterogenous. Fair.	Dominant knee average hamstring tightness in female cricketers is 9.4±6.563°. Dominant knee hamstring tightness is significantly higher in male cricketers than in females, with $p<0.001$. Non-dominant knee average hamstring tightness in female cricketers is 11.2±6.994 °, and in male cricketers, it is 17.6±4.804. Female cricketers have greater hamstring flexibility than male cricketers with lower back pain.	Athletes with good hamstring flexibility may have lower maximal hamstring muscle strains. Also, athletes with good hamstring flexibility may have a lower risk of hamstring injury than those with poor hamstring flexibility.

BBL (Big Bash League), C5 ratio (The Five Club Concentration), ECB (England Cricket Board), ER (external rotation), IR (internal rotation), LBP (lower back pain), ODI (One Day International), UK (United Kingdom), WBBL (Women's Big Bash League).

Supplementary Table 3-5. Study characteristics of match characteristics studies included in the scoping review (n=5)

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
Bhardwaj and Dwyer (2022)	Australia, National level (n=180 innings)	The study's primary aim is to identify the optimal technical characteristics of teams in T20 cricket. In addition, we aim to address several limitations of previous analyses. We propose using a more comprehensive range (>35) of technical performance indicators, hundreds of matches, and women's cricket data. Thus, this study uses the Australian Big Bash League (BBL) and Women's Big Bash League (WBBL) T20 professional leagues. Finally, we looked at a team's optimal characteristics in one match and over a season. 2019-2021	Technical performance data provided by Cricket Australia. The data was provided in a ball-by-ball structure, which included over and ball number, ball type (e.g. no-ball), and each ball's outcome (e.g. 2 runs or the loss of a wicket).	Male and female. Homogenous. Good.	In the context of women's T20 cricket, it is evident that batting performance characteristics are more significant than bowling. The most crucial bowling characteristic is the speed at which the first 3 to 5 batters are dismissed. The determinants of match outcome also serve as indicators for explaining overall performance throughout the season. The factors influencing performance in women's T20 cricket are like those in men's cricket. However, certain women's teams may benefit from emphasising bowling performance as a critical aspect of their match strategy.	This study offers insights into the significance of various performance indicators that can be utilised by teams and analysts for goal setting and designing performance analysis systems.
Gupta (2022)	India, National level (n=56)	This study aims to quantify women's batting performances in one-day international (ODI) matches. 1973-2021	Gini coefficient-based average method, Principal Component Analysis framework. Cricinfo database.	Female only. Homogenous. Fair.	As a result, Principal Component Analysis combined with Gini scores can assist cricket fans, coaches, and managers better understanding a player's performance.	-
Jadhav and Raizada (2020)	India, National level, study sample not indicated.	This research aims to understand the global trend of competitive balance in Domestic One Day Women's Cricket Competition by using the Five Club concentration ratio (C5) and the C5 index of competitive balance. 2015-2019	Data was obtained from online cricket databases, namely Cricbuzz and Cricinfo, and official sites, such as the BCCI and New Zealand Cricket. Competitive balance is measured by quantifying competitive balance using factors such as The Five Club Concentration (C5 ratio) and the C5 index of competitive balance.	Female only. Heterogenous. Poor.	Using the C5ICB index, the results exhibited the highest and lowest competitive balance between countries, which were New Zealand (107.52), Australia (124.86), England (142.22) and India (167.23).	Governing bodies must ensure the maintenance of competitive balance in these matches. The governing bodies of countries should establish additional domestic leagues to enhance the exposure of female cricketers at the domestic level. Improving competition at the grassroots level will enhance competitive balance at the international level by ensuring that only the most talented individuals reach the highest level.
Munro (2019a)	South Africa, National level, study sample not indicated.	Determine and quantify the motion demands of female batters during ODI and T20 cricket matches. Determine the breakdown of a century scored	Time-motion analyses were conducted on one-day international and T20 innings. The observations were made using recordings obtained	Female only. Homogenous. Good.	The average ODI innings lasted 169 minutes, according to time-motion analyses. An over lasted 2.45 minutes, with 24.86 seconds between deliveries and 55 seconds between overs. It took 1.12 minutes between overs when the bowlers changed. An ODI's average first power-play	The study found that the movement requirements in women's cricket differ from those in men's cricket, specifically in the One Day International (ODI) and Twenty20 (T20) formats. Moreover, the demands vary based

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
		in ODI matches and the breakdown of a half-century scored by female batters in T20 matches and establish a simulated batting training protocol for female cricket players. 2012-2017	from the public domain, with permission from Cricket South Africa and the licensed broadcaster SuperSport.		score was 41 runs with 1.38 wickets. The mean second power play score was 28 runs with 0.714 wickets. The T20 bowling innings lasted 75.50 minutes, with 2.52 minutes per over and 25.58 seconds between deliveries. The average T20 batting innings score was 122. In the 24-35-minute power play, 37 runs were scored with 1.45 wickets. Using four stages, the simulated batting innings lasted a typical women's century.	on the participating country. Developing a specialised training and research protocol for female batters is a significant achievement.
Nicholls et al. (2023)	UK (England), National level, (n=31)	This study aimed to analyse specific batting demands and variables associated with the women's The Hundred competition. 2021	A bespoke panel was created within Hudl Sportscode Elite (Hudl, USA) to code each game and associated variables of interest.	Female only. Homogenous. Good.	A significant difference ($p<0.05$) was observed for the time between deliveries for spin bowlers (26.90±22.16 s) compared to seam bowlers (31.70±20.37 s) as well as the time between sets for the power play (58.00±13.28 s) and non-power play phases (63.70±42.00 s). In the power play, most runs comprised "1's" and "4's". In the non-power play phase, "1s" made up the most significant contribution of runs (as a percentage).	Training programs should develop bioenergetics for movement demands and simulate match situations to prepare players for unpredictable cricket and skill execution under fatigue. In women's cricket, workload demands are higher than men's, making this crucial. This research could enable the creation of training protocols that mimic specific phases of play. Well-designed programs can reduce injury risk and enhance player performance and well-being. Developing upper body strength and power is crucial for frequent boundary clearing. To improve acceleration, training should prioritise force development in the lower limbs.

BBL (Big Bash League), C5 ratio (The Five Club Concentration), ECB (England Cricket Board), LBP (low back pain), ODI (One Day International), T20 (Twenty20), UK (United Kingdom), USA (United States of America), WBBL (Women's Big Bash League).

Supplementary Table 3-6. Study characteristics of nutrition and hydration studies included in the scoping review (n=2)

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
Sobana (2016)	India, Club level (n=45)	The purpose of this study was to determine differences in nutrition knowledge between collegiate athletes participating in different types of sports, identify areas where nutrition knowledge was lacking and investigate nutrition-related concerns athletes would like to have addressed. 2016	A self-structured questionnaire was framed by the investigator based on the common dietary practices of the sportspersons.	Male and female. Homogenous. Good.	Sports nutrition knowledge was low, with females scoring higher than males. Female cricketers knew the most about carbohydrates, lipids, vitamins, fluids, weight management, and eating disorders. Only 13% of female cricketers disagreed that skipping meals is best for weight loss. Their incorrect attitude towards weight management practices is evident. Most female players (54%) agreed that female athletes need more iron. The current study found that 10% of female players eat a balanced diet. 74% of female players did not carbo-load. Most female players (61%) skip meals before competition. Fear of stomach upset prompted meal skipping. 14% of female players took performance supplements. 8% of female cricketers recover with healthy food.	The low sports nutrition scores of female cricket players suggest the need for ongoing nutrition education from a sports nutritionist to enhance their overall health and performance in sports. The findings indicate inadequate adherence to dietary practices among female cricket players.
Soo and Naughton (2007)	Australia, National and state level (n=18)	Our twofold objectives were to advance the understanding of fluid losses in cricket sessions across a tournament and assess the hydration knowledge and practices in high-performance female cricket players. This information could then be used to enhance education on specific hydration guidelines and strategies for women in cricket. 2007	The study consisted of 2 components: tournament-related body-mass and urine-specific-gravity measurements and a questionnaire assessing hydration knowledge and habitual practices. Urine-specific gravity was determined using an optical refractometer. Body mass was measured using digital scales accurate to 50g and 100g.	Female only. Homogeneous. Good.	Body-mass losses characterised most innings (69%), but there were some increases in body mass (28% of innings). Two players did not gain mass at any stage of the tournament, and 13 out of 18 increased their body mass over an inning on 1 or 2 occasions. One player gained mass four times in 4 innings. The sweat rate for the first inning of game day one was calculated as 0.24 ± 0.21 L/h, but as already presented, when the total sweat loss was divided by actual time on the field, a value of 0.78 ± 0.65 L/h resulted. Based on exact activity time, sweat-rate values were comparable to other female team athletes but lower than male cricketers.	Monitoring body mass changes during matches and in different environmental conditions would help players accurately determine their fluid needs. Enhancing education for players, coaches, and umpires, along with implementing local competition-rule modifications, can reduce the likelihood of performance decline due to hydration issues and mitigate the occurrence of severe medical complications. Implementing a reporting system for heat- and dehydration-related illnesses would facilitate the determination of the frequency of these occurrences, thereby aiding in the formulation of future policies and regulations.

Supplementary Table 3-7. Study characteristics of performance studies included in the scoping review (n=45)

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
Physical strength capacity (n=16)						
Boby (2023a)	Bangladesh, Division level (n=30)	The goal of the current study, which considered the significance of motor fitness and sports performance, was to examine the association between certain motor fitness factors and sports performance among high-performing female cricketers. Year of study not reported.	The motor fitness variables, including agility, abdominal strength, speed, arm strength, and cardiovascular endurance, were assessed using the shuttle run (4X10 Yard), sit-ups, 50-yard dash, medicine ball throw, and 9-minute run/walk tests, Respectively.	Female only. Homogenous. Fair.	The study found a significant positive correlation between motor fitness and sports performance in elite female cricket players. The study found that abdominal strength, speed, and cardiovascular endurance positively impact the performance of cricket players in competition. There was little to no correlation between arm strength, agility, and improved athletic performance in elite female cricketers. The results indicate that enhancing motor fitness, particularly abdominal strength, speed, and cardiovascular endurance, could enhance the athletic performance of elite female cricket players.	This study identifies the key motor skills that significantly contribute to the success of situational motor skills in female cricket players. The findings suggest that this research can enhance the safety and effectiveness of training programs for these players.
Boby and Badhan (2022)	Bangladesh, Division level (n=40)	Assess the motor fitness parameters among female cricket players from Bangladesh's Bogura and Khulna districts. Year of study not reported.	Sergeant jump for leg explosive strength and 4x10yd shuttle run for agility.	Female only. Homogenous. Poor.	The results suggest notable disparities in leg explosive strength between female cricket players from Bogura and Khulna. This is supported by the t-value, which exceeds the critical value 2.02. The study found that Bogura women's cricket players exhibit superior explosive leg strength compared to Khulna. The practice environment, encompassing various practice settings, may influence the results. No significant difference in agility was found between the students from Bogura and Khulna. The current findings highlight the superior attributes of Bogura students compared to those from Khulna.	The study's findings can inform strength and conditioning coaches on how to improve individual training.
Boby (2023b)	Bangladesh, State level (n=36)	The study aimed to compare the players from the Bangladesh Women's National Cricket League teams from Khulna, Sylhet, and Dhaka to see if there were any considerable differences in their performance capabilities and motor fitness characteristics. 2022-2023	Questionnaire on Cooper 12min run, 50 Yard Dash, Shuttle run, Standing broad jump.	Female only. Homogenous. Good.	The results of the study showed that there were significant differences in motor fitness characteristics between high and low-performing Divisional female cricket players. High-performing players had significantly better scores on cardiovascular endurance (p=.000), explosive leg power (p=.013), speed (p=.002), and agility (p=.000) than low-performing players. The league's Champion Team (Sylhet) was discovered to be more successful than other teams in achieving high-level performance.	Our study may contribute to safer and more effective training for young female cricket players by enabling us to pinpoint the core motor skills primarily responsible for successfully executing situational motor abilities.
Chanda et al. (2018)	Bangladesh, National level (n=30)	This study aims to investigate the physical fitness status of the current women players of Bangladesh	AAHPHERD test batteries (50y dash, shuttle run,	Female only. Homogenous. Fair.	The results showed that 38.66% had good physical fitness, 23.33% had very good physical fitness, 4.66% had an outstanding level of	-

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
		women's national team and compare the fitness components. Year of study not reported.	and sit-up), beep test and 9 Minutes run.		physical fitness, 12.66% had average physical fitness, 13.33% had satisfactory overall fitness, and 9.33% had poor physical fitness. The mean values of Bangladesh national female cricket were found to be higher in all parameters when compared to the 50th percentile norms of the mentioned variables.	
Chaurasiya and Mehta (2018b)	India, State level (n=50)	The study aimed to examine the effect of core stability exercises in enhancing the upper and lower body strength of female cricket players. Year of study not reported.	For the fitness assessment test, upper and lower strength was measured by Shoulder, Arm, Abdominal, Left & Right hand grip, and Back and Leg Strength.	Female only. Homogenous. Fair.	The study found that Swiss ball core stability training improved female cricketers' upper and lower body strength. However, it is important to note that the scope of the study limits this conclusion. The study found a significant ($p<0.05$) effect of Swiss ball core stability training on seven strength variables in female cricket players. The training program led to significant improvements in upper and lower body strength, except for back strength.	The core stability training program notably impacts upper body strength variables. The core stability training program notably affects various lower body strength variables, except for back strength.
Chaurasiya and Mehta (2018a)	India, National level (n=20)	The study aimed to compare the selected strength variables among female bowlers and batters in cricket. Year of study not reported.	The strength variables included shoulder, arm, abdominal, left hand grip, right hand grip, back, and leg strength.	Female only. Heterogenous. Fair.	The findings indicate that female cricket bowlers possess greater shoulder strength than batters. This could be attributed to the specific role they assume in the game. Bowlers must consistently deliver balls to batters, necessitating rigorous practice to enhance their shoulder muscles, enabling them to achieve higher ball speeds. The batters' focus on batting may explain the notable differences between the two groups. The group of batsmen exhibits superior right grip strength. Since all the batters were right-handed, their grip strength was expected to be considerably more significant than the bowlers.	-
Das and Bidua (2019)	India, Club level (n=15)	The aim of the present study was to compare the agility between 15 female Football and 15 female cricket Players of LNIPE Gwalior. 2018-2019	Semo agility test is used to collect the data for Agility.	Female only. Homogenous. Fair.	The Semo agility test was utilised to evaluate the agility of football and cricket players. The study found no significant difference between female football and cricket players. Speed training is recommended for football and cricket players to improve their performance.	-
Dibba and Ganapathi (2023)	India, Provincial level (n=16)	The study aimed to evaluate the effect of replacing a part of the usual six-week cricket conditioning regimen with simulation-based training on some physical fitness components, including aerobic and anaerobic power, agility, speed, explosive leg strength, and BEST measurements among	The experimental group participated in a six-week cricket simulation training program, including running at different speeds (jogging to sprinting), agility, jumping, and shuffling. Control and	Female only. Homogenous. Good.	The level of perceived exertion was significantly higher in the simulation-based training group compared to the control group ($p<0.05$). The study found significant improvements in VO_2 max anaerobic power, explosive leg strength, total distance covered in a cricket exercise simulation test, and a decrease in the time taken for one round of the cricket exercise simulation test in the	-

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
		professional cricket players. The year of study is not reported.	experimental groups performed typical cricket training three times weekly. Both groups underwent physical tests, including the Cooper 12-minute run, line drill, adjusted T-test, 20 ms print, Sargent vertical jump, and cricket exercise simulation test.		simulation training group compared to the control group ($p<0.05$).	
Gayatri and Sarojini (2022)	India, Junior and club level (n=90)	The study aimed to determine the effect of plyometric training with yogic practices and plyometric training without yogic practices on physical fitness variables among female cricket players. Year of study not reported.	The experimental groups underwent plyometric training with yogic practices and plyometric training without yogic practices for eight weeks, three days per week, with a daily session. Testing was measured by speed and agility through a 50-yard dash and shuttle run test.	Female only. Heterogenous. Fair.	The study found that both plyometric training with yogic practices and plyometric training without yogic practices led to a significant improvement in speed and agility after eight weeks of training. Nevertheless, the training groups exhibited a negligible disparity.	-
Letter et al. (2022a)	Australia, National and state level (n=31)	This study investigated the differences between selected physical attributes and ball release speed in slower and faster male and female elite pace bowlers. 2015-2020	Ball Release Speed - peak ball release speed of each delivery was measured by a radar gun (Stalker Pro; Applied Concepts, Richardson, TX). physical attributes were collected per Cricket Australia's standardised testing protocols (2km TT, CMJ, Bench pull, Isometric-Mid thigh pull, Run of 3.	Male and female. Heterogenous. Good.	Faster female pace bowlers demonstrated significant differences in their performance compared to slower-pace bowlers. These differences were observed in various measures, including an average run of 3 performance, the best run of 3 performance, IMTP peak force, and 1RM bench pull. The effect sizes for these differences ranged from moderate to small. The faster-pace bowlers exhibited variations in isometric midthigh-pull peak force. Similarly, there were differences in relative peak force, with effect sizes of $d = 0.62$ in males and $d = 0.77$ in females. Male faster-pace bowlers showed variations in relative ($d = 0.61$) and absolute ($d = 0.39$) countermovement jump heights. Female pace bowlers who exhibited faster speeds showed variations in their bench pull strength and performance in a run-of-3	This study identifies physical attributes for each gender that coaches can target to improve ball release speed. Improving lower body strength, anaerobic capacities, and upper body pulling strength can benefit female pace bowlers. Research suggests that female pace bowlers may benefit from increased lower body strength, enabling them to use a technique similar to male bowlers and achieve faster ball release speeds.
Letter et al. (2022b)	Australia, National and	To determine whether the most important physical qualities in elite Australian male and female cricket	Male and female physical testing data from the isometric midthigh pull, 1-	Male and female. Heterogenous. Good.	A significant age effect was found for all physical qualities. There was no significant interaction effect (age × season phase) for physical quality.	Physical qualities of both male and female pace bowlers generally improve with age. This phenomenon is

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	state level (n=58)	pace bowlers change with age and phase of the cricket season. 2014-2021	repetition-maximum bench pull, run-of-3, and countermovement jump (male only) were analysed separately by performing linear mixed models on each of the physical qualities.		The absolute and relative peak force from the IMTP was significantly lower in age group 18 compared to other age groups. Run-of-3 performance was significantly higher in female pace bowlers aged 28 and 29 than those aged 18-22. From 18 to 30 years old, there were slight improvements in best and average run-of-3 performance. Age groups 18-22 had significantly lower absolute and relative 1RM bench pull strength than older groups. Significantly higher absolute and relative 1RM bench pull strength occurred during the in-season phase compared to the off-season phase. There was no significant difference between in-season and off-season phases for other physical qualities.	likely a result of training, which is expected to gradually improve ball release speed, as supported by previous studies.
Raj and Sudheer (2016)	India, Club level (n=20)	The purpose of the present study was to determine the effect of strength training on the arm strength of female cricket players. Year of study not reported.	The strength training is increased by doing chest, shoulders, triceps, biceps, and abs.	Female only. Heterogenous. Fair.	The study found a significant difference in arm strength because of strength training. The study employed a 12-week program consisting of three sessions. It observed an increase in arm strength because of strength training. The study findings and existing literature support the conclusion that strength training significantly enhances arm strength, as measured by the criterion variable.	Strength training is an effective method for enhancing arm strength and overall physical fitness in female cricket players.
Reddu (2016a)	India, Club level (n=20)	The study aimed to compare the agility ability of the coordinative variables of female cricket players at different levels. Year of study not reported.	Only one coordinate ability variable was considered to establish the effect of circuit training and interval training vascular endurance.	Male and female. Homogenous. Poor.	The average agility score for high school boys was 14.66, and for girls, 17.66. Male high school cricket players had a 0.92 standard deviation of self-practice scores, while females had 0.57. A 13.43 t-value exceeded the critical value of 1.96. The hypothesis failed at 0.05. Male and female high-self-practice cricket players from state and intercollegiate institutions are equally agile. Self-practice factor of balance is similar for male and female state and intercollege students. Agility differed significantly between males and females.	-
Singh (2016b)	India, All levels (n=50)	This study aims to compare the physical fitness components of female cricket and baseball players, specifically focusing on speed, explosive strength, and cardiovascular endurance. This study examines the disparities in psychomotor ability and concentration levels between female cricket players and baseball players. 2008-2011	Blood pressure (both) with stethoscope, and sphygmomanometer. Pulse rate with digital pulse rate monitor. Respiratory rate and breath holding with Swiss standard stopwatch.	Female only. Heterogenous. Fair.	Baseball players exhibit greater speed and cardiovascular endurance compared to cricket players. Cricket players show higher explosive strength compared to baseball players. The psychomotor abilities of baseball and cricket players are similar. Cricket players exhibit higher levels of concentration compared to baseball players. There are notable variations in the speed, cardiovascular endurance, explosive strength, and concentration abilities between baseball and	-

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					cricket players. There is no significant difference in the psychomotor ability between Baseball and Cricket players.	
Sunble et al. (2022)	Pakistan, Junior level (n=54)	This study was designed to determine the effects of periodized resistance training on sprinting speed, agility, and power in young domestic female cricketers. 2019-2020	Run-a-Three, Illinois agility, and Sargent jump tests was used. The experimental group engaged in prescribed exercises three times a week for 60 minutes over eight weeks, alongside regular fitness training. After the eight weeks, power, agility, and sprinting speed were re-evaluated.	Female only. Homogenous. Good.	Run-a-three test shows that periodised resistance training increases sprinting speed ($p = 0.01$). The post-intervention mean±SD of the Illinois agility test was 19.817±1.579, indicating a significant effect of periodised resistance training on agility (The post-intervention mean±SD of the sergeant jump test was 7.782±2.448, showing a substantial impact of periodised resistance training on lower limb power (The post-intervention mean±SD of seated medicine ball throw was 28.194±3.878, indicating no significant effect of periodised resistance training on upper limb power ($p=0.89$).	Periodised resistance training can enhance the sprinting speed, agility, and lower limb power of young female cricketers when incorporated into their fitness training program.
Thomas et al. (2017)	UK, Not specified (n=23)	Therefore, this study aimed to compare the CMJ-PF, IMTP-PF, and resultant DSI values between team-sport athletes. Year of study not reported.	Countermovement Jump Testing (CMJ) and Isometric Mid-Thigh Pull Testing (IMTP)	Male and female. Heterogenous. Good	Male cricket players produced greater CMJ-PF compared to those produced by the female netball ($p = 0.050$; $d = 0.63$), and female cricket ($p < 0.001$; $d = 1.13$). Finally, female netball players produced greater CMJ-PF than female cricket players ($p = 0.005$; $d = 0.61$). Male cricket players produced greater IMTP-PF than female cricket players ($p < 0.001$; $d = 1.37$). Female netball players produced greater CMJ-PF than female cricket players ($p = 0.003$; $d = 0.74$).	The study's findings suggest that athletes' strength levels cannot be determined solely based on their DSI ratio. Instead, researchers and practitioners should focus on monitoring relative changes in CMJ-PF and IMTP-PF.
Biomechanics (n=14)						
Alway et al. (2022)	UK (England), National level (n=6)	Determine if there are differences in body or bat kinematics against fast and spin bowling in elite female cricket batters. Year of study not reported.	Testing was conducted in an indoor cricket specific facility, on a full-sized artificial cricket pitch. Kinematic data were recorded using an 18-camera Vicon Motion Analysis System (OMG Plc, Oxford UK) operating at 250 Hz	Female only. Homogenous. Fair.	Batting against spin increased carry distance. Its vertical launch angle was nearly higher than batting against fast bowling. Group bat and ball variables did not differ further. Batting against spin bowling produced significantly less top wrist radial deviation at impact, greater ulnar deviation between maximum radial deviation and impact, and greater whole-body centre of mass anterior displacement towards the bowler between stance and impact than fast bowling. The X-Factor separation between the top of the downswing and the maximum value was significantly higher against spin bowling than fast bowling. No other wrist, elbow, X-Factor or downswing duration differences were found.	Coaches should note that elite female batters use different techniques when facing spin and fast bowling.

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
Bailey et al. (2023)	Australia, National level (n=28)	Analyse in-match data from wearable devices (gyroscope, accelerometer, and global positioning system (GPS)) and ball velocity data over a season to determine whether the run-up and delivery stride characteristics were associated with ball velocity in elite female pace bowlers. 2019-2020	Bowler's run-velocity was measured by the Catapult Optimeye S5 GPS unit (Catapult Innovations, Melbourne, Australia) that was held within a GPS vest worn across the bowlers' upper back.	Female only. Homogenous. Good.	Univariate analyses revealed that run-up velocity metrics, run-up distance, and peak resultant acceleration ($p = 0.013$) strongly predicted absolute ball velocity. Age, bench pull, vertical jump, and mid-thigh pull for the season did not independently explain absolute ball velocity variance. Bench pull, vertical jump, and mid-thigh pull did not predict run-up velocity metrics, except for bench pull and maximum run-up velocity. In multivariate analysis for absolute ball velocity, average and maximum run-up velocity were collinear with maximum velocity during a delivery stride. Maximum velocity during delivery stride, peak resultant acceleration, run-up distance, and peak roll strongly predicted absolute ball velocity. The average, full, and maximum run-up and delivery speeds strongly predicted the relative ball velocity.	Comprehending the run-velocity parameters in female pace bowlers with varying anthropometric characteristics, strength, and bowling biomechanics is crucial.
Felton et al. (2019)	UK (England), National level (n=20)	This study aims to compare the performance (ball release speed) and the kinematics of the fast-bowling action between elite male and female fast bowlers to determine whether differences in techniques exist. Year of study not reported.	Each bowler had 47 retro-reflective markers measuring 14 mm attached to their bodies, following the marker set used by Worthington et al. (2013a). A 15 x 15 mm reflective patch was affixed to the ball using 3M Scotch-Lite reflective tape. This allowed for measuring ball release speed and the moment of release. The study recorded six deliveries of maximal velocity using an 18-camera Vicon Motion Analysis System (OMG PLC, Oxford, UK) operating at 300 Hz.	Male and female. Homogenous. Good.	Female fast bowlers exhibited slower ball release speeds than male fast bowlers. On average, female fast bowlers were notably shorter and lighter than their male counterparts despite their similar age. The results suggest that female bowlers produced lower whole-body linear momentum during the run-up than males. Male bowlers employed a technique between BFC and FFC that better preserved linear momentum than the females. Due to the disparity in linear momentum at FFC, females tended to use a throwing technique that involving whole-body angular momentum and large rotator muscles to rotate the pelvis and torso segments around the longitudinal axis, resulting in increased ball release speed.	The results presented by this study have potential applications in coaching female fast bowlers. However, further research is needed to fully comprehend the impact of anthropometric and strength limitations on fast bowling performance.
Hamilton-Hastings (2011)	Wales, Club level (n=4)	This study aimed to identify significant relationships between selected upper body kinematic variables and ball release speed for female bowlers. Year of study not reported.	CODAmotion analysis system (Charnwood Dynamics Ltd, Leicestershire, UK) sampled at 200Hz with four CODA scanners set	Female only. Homogenous. Fair.	Increased elbow flexion and extension did not affect ball release speed or height as a percentage of standing height, suggesting that coaches could prioritize straight elbows over ball release height to reduce injury risk. Previously published research indicate that the vertical	The findings of this study have practical implications for coaching and conditioning female fast bowlers, as well as junior bowlers who are still developing their physical characteristics and strength.

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			up surrounding the force plates sampled at 1000Hz to record the trials & Force plates.		velocity of the non-bowling elbow increases ball release speed (p = 0.045; 0.024). The maximum height reached by the non-bowling arm as a percentage of standing height and the vertical velocity of the elbow (p = 0.008), bowling arm (p = 0.000), and ball release speed (p = 0.05) may be causally related.	
King and Yeadon (2012)	UK (England), National level (n=1)	This study aimed to develop an appropriate method for determining the amount of elbow extension/ hyperextension and elbow abduction for a bowling delivery, to apply the method to Jenny Gunn who has hypermobility in both elbows, and to quantify the accuracy of the calculated angles. 2007	Anthropometric assessments and Bowling analysis using a motion analysis system. Vicon Motion Analysis System (OMG Plc, Oxford, UK) operating at 250 Hz (April 2007) and 300 Hz	Female only. Homogenous. Fair.	Significant discrepancies were observed in elbow extension (up to 18 degrees) and elbow abduction (up to 28 degrees) between the angles calculated from the marker set used in static straight arm trials and the measurements obtained by a certified sports physiotherapist. The comparison of elbow extension angles at ball release, calculated from markers during bowling trials, with those measured from high-speed video demonstrated a strong agreement.	This study addresses several issues that are not considered by the current ICC protocols. The method used in this study has been shown to produce consistent results for a bowler with an unconventional bowling action in two sessions conducted 18 months apart. In the future, comparing angles calculated using current International Cricket Council (ICC) protocols with those obtained from the method proposed in this paper.
Liu et al. (2010)	China, National level (n=7)	Analyse the bowling technique of the Chinese female bowlers from the aspects of bowling speed, angle of the bowling arm, bowling stride position and length, body gesture at landing, joint angle at ball release, etc. Year of study not reported.	APSS system to analyse pitching technique images. Dartfish analysis software was used to determine body joint angles.	Female only. Homogeneity. Fair.	The findings indicate a significant variation in the technical characteristics among bowlers of different types. The duration between the moment fast bowler lands and releases the ball is shorter than that of spin bowlers. Elite bowlers' landing positions and body gestures are more stable than lower-level bowlers. Additionally, it is important to note certain technical deficiencies, such as knee collapse during ball release, bending of the elbow, and faults in the front foot.	-
Lyons et al. (2023)	Ireland, National and provincial level (n=11)	To investigate the association between key male-derived kinematic and anthropometric parameters and ball release speed (BRS) in female pace bowlers. Year of study not reported.	Six maximal effort deliveries targeted at a good length were recorded using two iPhone 11 video recorders (Apple Inc, California, USA) capturing at 240 Hz. Each iPhone was mounted on a tripod at a height of 0.91 m and placed 6 m perpendicular to the sagittal plane on either side of the bowling crease, so the optical axis aligned with the plane of	Female only. Homogeneity. Good.	The bowling shoulder angle at ball release was the most significant predictor of BRS, accounting for 89% of the observed variance. Height was the most accurate anthropometric predictor of BRS, accounting for 53% of the observed variance. Additional parameters that showed correlation with BRS were run-up speed and arm length. After accounting for height, there was a significant correlation between the front knee angle at front foot contact and BRS. There was no correlation between trunk flexion and baroreflex sensitivity (BRS).	Faster BRS exhibited higher run-up velocities, more linear front knee movements, and a delayed arm circumduction pattern resembling male pace bowlers. The absence of a correlation between trunk flexion and BRS suggests that female pace bowlers may employ a bowling technique in which trunk rotation and trunk flexion contribute to BRS. This knowledge is valuable for identifying and coaching female pace bowlers.

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
			motion of the bowler during the delivery.			
McErlain-Naylor et al. (2021)	UK, University and elite (n=15)	The study compares power-hitting kinematics between skilled male and female cricket batters while controlling for differences in body mass and height. Year of study not reported.	Kinematic data were recorded using an 18 camera Vicon Motion Analysis System (OMG Plc, Oxford, UK) operating at 250 Hz.	Male and female. Heterogeneity. Good.	Gender significantly affected maximum bat speed, and ball carry distance, with male batters outperforming female batters. Gender significantly affected pelvis-thorax transverse plane separation and lead elbow extension during the downswing in batters. However, there was no significant effect of gender on wrist uncocking from minimum angle to impact. Sex significantly affected bat angle, rear elbow angle, and X-factor reduction in batters. Male batters performed better than female batters in these aspects. Gender did not have a significant effect on the other kinematic parameters.	During the downswing, only the female batters demonstrated the flexion of their lead elbow, while the male batters did not. There was no observed effect of gender on wrist uncocking during the downswing. The differences in power hitting between male and female cricket players are likely to be influenced by various factors, including individual characteristics, equipment used, the nature of the task, and the players' training and coaching history.
Savage and Portus (2002a)	Australia, National level (n=5)	The purpose of this study was to identify the bowling techniques used by female bowlers and compare these to results published for male fast bowlers. Year of study not reported.	Filmed using two synchronized cameras operating at 125 Hz (Redlake Imaging Corporation, USA) at the Australian Institute of Sport Biomechanics Laboratory	Female only. Homogenous. Fair..	A mean run-up speed of 4.9ms-1 recorded in this study indicates these female bowlers approached at a similar or slightly slower speed than reported approach speeds for males. The mean ball release speed of 27 ms-1 recorded for this group was slower than that reported for senior male bowlers. The mean shoulder alignment at BFC for this group of fast bowlers was 222°. Following BFC, there was a counter-rotation of the shoulders to a mean minimum shoulder angle of 193°. Examination of the bowlers concerning the technique classification criteria resulted in two bowlers being classified as front-on. The remaining three bowlers were classified as mixed, with two having a shoulder counter-rotation of more than 40° following BFC and the remaining bowler having a hip-shoulder separation angle of more than 20° at BFC. No bowlers were classified as using the side-on technique in this study.	-
Stuelcken and Sinclair (2009)	Australia, National level (n=15)	The aims of this pilot study were to: (1) provide normative data on the magnitude of front foot ground reaction force variables in elite female fast bowlers; (2) determine the number of trials required to obtain stable front foot ground reaction force measures in these bowlers; and (3) determine the validity of normalizing front foot ground reaction force data using body mass	A 900mm×600mm piezoelectric force platform (Type Z 12697; Kistler Instrumente AG, Winterhur, Switzerland) was recessed beneath the front bowling crease and covered with a piece of polyflex surface (International Athletic	Female only. Homogenous. Good.	The statistical analyses indicated that variations in body mass accounted for a small proportion of the variability in peak vertical force (2.3%) and peak horizontal braking force (2.0%). Of 15 bowlers, 10 demonstrated a heel-toe striking pattern, while 5 exhibited a foot-flat striking pattern. The average peak vertical ground reaction force was 3.49 kN (±0.81) and the average peak horizontal braking force was 2.13 kN (±0.52). The statistical analysis showed that body mass accounted for a small	Female elite fast bowlers exhibit lower front-foot ground reaction forces compared to male elite fast bowlers. Performance stability across the selected front foot ground reaction force variables was achieved after twelve trials. The body mass of elite female fast bowlers has minimal impact on the magnitude of front foot ground reaction forces.

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		as a covariate in these bowlers. Year of study not reported.	Federation Standard) that was 0.017m thick. Ground reaction force data were sampled at 1080 Hz.		portion of the variation in peak vertical and horizontal braking forces in elite female fast bowlers (2.3% and 2.0%, respectively). The average time to reach the peak vertical force was 0.033 s (±0.009), and the vertical loading rate was 121.31 kN s−1 (±73.78).	
Stuelcken et al. (2010a)	Australia, National level (n=18)	The study aims to quantify the magnitude of the peak shoulder distraction force in the fast bowling action. Year of study not reported.	Vicon motion analysis system operating at 120 Hz recorded the fast bowling actions of 18 Australian female fast bowlers.	Female only. Homogenous. Good.	A significant peak shoulder distraction force was observed in the initial stages of the follow-through in the bowling action. The maximum shoulder distraction force was measured to be 599 N ± 111, occurring at an average bowling arm angle of 27° ± 15 past the vertical. The average bowling arm angle at ball release was 15° ± 5 past the vertical. The shoulder distraction force typically reaches its highest point in the early stages of the follow-through. The average ball speed at release was 26 m/s ± 1.	-
Stuelcken et al. (2010b)	Australia, National level (n=26)	This study aimed to (1) analyse the movement patterns of the thorax and pelvis of elite Australian female fast bowlers and classify the techniques of these bowlers according to criteria previously established for male fast bowlers, and (2) determine whether there is an association between a history of LBP and the movement patterns of the thorax relative to the pelvis during the delivery stride of the bowling action. Year of study not reported.	Three-dimensional kinematic data were collected from 26 elite Australian female fast bowlers using an eight-camera Vicon motion analysis system.	Female only. Homogenous. Good.	Nineteen bowlers used a mixed action, 6 bowlers used a semi-open action, and 1 bowler used a side-on action. Fourteen bowlers had a history of LBP. Eight of these 14 bowlers used a mixed action, and bowlers with more shoulder counterrotation were no more likely to have a history of LBP. Bowlers with a history of LBP positioned the thorax in more left lateral flexion relative to the pelvis between 73–79% of the delivery stride. They moved the thorax through a significantly greater range of lateral flexion relative to the pelvis during the delivery stride compared to bowlers with no history of LBP.	This information will give coaches and support staff a better understanding of female bowling techniques and may facilitate better screening practices for elite female cricketers.
Wood (2010)	UK (Wales), National and club level (n=4)	The aim of this study was to enhance the understanding of kinematic and kinetic variables reported to significantly increase the risk of lower back injury in female bowlers. Year of study not reported.	CODA Motion Analysis System (Charnwood Dynamics, Leicester, UK) and two piezoelectric Kistler Force Platforms (Kistler, Winterthur, Switzerland).	Female only. Homogenous. Fair.	One participant was categorized as mixed due to a hip-shoulder alignment over 30º at back foot impact, while the other three were side-on bowlers. According to Pearson's product-moment correlation coefficients, knee and hip angles did not correlate with vertical ground reaction force at front foot impact, ball release, or hip-shoulder separation angles and shoulder counter-rotation. A higher shoulder alignment angle at the back foot impact reduced hip-shoulder separation and increased shoulder counter-rotation during delivery. This suggests that a side-on alignment at back foot impact may reduce injury.	-

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Felton et al. (2015)	UK (England), National level (n=18)	To investigate the relationships between female fast bowling technique and ball release speed. Year of study not reported.	Vicon Motion Analysis system was used to collect three-dimensional kinematic data.	Female only. Homogenous. Good.	Three technique variables, namely run-up speed, knee angle at ball release, and shoulder angle at front foot contact, accounted for most of the variation in ball release speed, explaining 74.1% of the observed variation. The fastest bowlers exhibited a quicker approach, increased knee flexion during ball release, and an earlier initiation of upper arm circumduction.	-
Training load/volume (n=2)						
Garcia-Byrne et al. (2020)	Australia, National, state and junior level (n=34)	This study aimed to determine the internal and external workloads of elite Australian women's cricket players (International, National and Youth) during T20 matches. 2016-2017	Catapult Optimeye S5 (Catapult Innovations, Melbourne, Australia) (International) or MinimaxX S4GPS (Catapult Innovations, Melbourne, Australia) device (National and Youth) GPS units, measuring Player Load and distance. Cellphone app to capture sRPE, Fairplay Athlete Management System, Fairplay Pty Ltd,Queensland, Australia	Female only. Heterogeneity. Good.	The distance covered during high-speed running (>21 km/h) was greater in international matches than in National and Youth matches. This was mainly because a longer distance was covered, ranging from 20.99 to 25.99 km/h. A consistent trend was found in various velocity bands, indicating that the distance covered generally increased as the level of competition advanced from Youth to National to International. Player load was significantly greater at the Inter-national and National levels compared to the Youth level. The sRPE (session rating of perceived exertion) was found to be higher at the Youth level. International and national matches have longer durations than youth matches. The study revealed notable variations in the distances covered by players across various skill levels. Players at the International level covered greater distances than those at the National and Youth levels. Significant differences were found in velocity bands 2 (1.02–14.0 km/h) and 4 (20.99–25.99 km/h).	The external workload of women's T20 cricket matches increases with higher levels of competition, from Youth to National to International. However, youth players perceive the match demands to be greater.
Hoyne et al. (2022)	Australia, State level (n=8)	The primary aim of this study was to determine the concurrent validity of player self-reported and externally observed throws in elite Australian Cricket players. The secondary aims were to determine whether sex, playing position, or time from training to self-report influence the accuracy of player self-reported throwing load. 2020-2021	Cricket Australia Athlete Management System (AMS) (Fair Play Pty Ltd)	Male and female. Homogeneity. Fair.	Female cricket players tended to report their throwing loads the day of training, whereas male cricket players tend to report their throwing loads the day following training.	This study suggests that relying on players' self-reported throwing loads may not accurately reflect their actual throwing loads, as most players had an error rate of over 10%. Therefore, high-performance staff and players should assess whether the current accuracy of self-reported throwing loads justifies the extra reporting effort during training.

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
Skill acquisition (n=7)						
Connor et al. (2020)	Australia, Junior level (n=260)	This study aimed to examine the magnitude of performance advantages associated with batting stance, in the form of left- vs. right-handed dominant stance and orthodox vs. reverse stance, in junior cricket players within age-restricted competitions. 2012-2015	Measures of batting performance were collated from the tournament database. Two measures of absolute performance were recorded: (i) batting aggregate, representing the total number of runs scored at the tournament, and (ii) number of innings batted. per innings).	Male and female. Heterogenous. Good.	Left-handed (LHD) and right-handed (RHD) batters performed similarly to younger players. LHD led older teams in batting aggregate, average runs per game, and batting time. Young reverse-batting female cricket batters had higher batting aggregate and time. The batting average of female batters in reverse stance was significantly higher ($p < 0.05$). Otherwise, reverse and orthodox younger age positions were similar. No older age performance measure showed significant stance differences, with effect sizes ranging from trivial to small-moderate.	Practical implications for coaches include creating practice environments that minimize the negative frequency effect, such as providing more practice opportunities against left-handed opponents.
Freeston et al. (2007)	Australia, State and club level (n=34)	The purpose of this study was to assess the throwing performance of elite and sub-elite cricket players at maximal throwing velocity, as well as throwing accuracy at various velocities relative to maximal throwing velocity. Specifically, we wished to determine whether a relationship exists between velocity and accuracy in a cricket-specific throwing test. Year of study not reported.	Injury questionnaire. Maximal throwing velocity test by Cordless Speed Radar Gun (Jugs Corporation, Tualatin, Oregon, USA, Throwing accuracy test to target	Male and female. Heterogenous. Good.	At 50% maximal throwing velocity, the elite under-19 females were significantly less accurate than the elite senior males (P50.01), elite under-19 males (P50.05), elite under-17 males (P50.01), and sub-elite senior males (P50.05). At self-selected velocities, the elite senior males were significantly more accurate than the elite under-19 females (P50.01). A comparison of elite senior males and females yielded a p-value of 0.065.	The findings suggest that factors such as sex, playing experience, and training volume may influence the throwing performance of cricket players. However, additional research is needed to investigate the underlying mechanisms behind the observed differences in throwing profiles and to explore the potential for improvement in these groups through training.
Lascu et al. (2022b)	Australia, Premier level (n=12)	Since club level cricket (amateur) is the stepping-stone of the talent development pathway for junior representative players pursuing elite status, it is important to evaluate the effectiveness of skill development practices at this level and identify improvement means. 2018-2019	The researcher developed a categorical assessment tool that evaluated ball delivery, decision-making, variability, and information sources to determine training session representativeness based on published research on skill development and expertise. The tool allowed for a scoring range of 0-3 with a maximum of 12 for bowling and 15 for batting. Head coach outlined KPIs were collected during the season to evaluate game	Female only. Homogenous. Good.	The limited variation in training design across the 21 sessions (<0.5 units on a 0-3 scale) prevented conducting a correlation analysis with game performance. Game key performance indicators (KPIs) were achieved inconsistently during the season. The training elements most representative of bowling included target, decision-making, and variability. Similarly, batting elements such as feed type and variability also performed well on the assessment tool. The maximum representativeness score for bowling or batting was not achieved, and the training design mainly remained the same throughout the season, despite variations in match type and competition phase, as well as consistently low scores in certain aspects.	The increasing professionalism in cricket and the growing career prospects for young female athletes will lead to a higher demand for talent development opportunities.

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
			performance and examine training design connections.			
Lascu et al. (2022b)	Australia, National level (n=16)	A representative sample of elite female cricketers and coaches in Australia were recruited to characterise current perceptions and practices of talent development in cricket for female athletes. Year of study not reported.	Semi-structured interview	Female only. Homogenous. Good.	Both players and coaches reported positive early learning experiences, linear career paths, and early talent program entry, indicating early specialization. Exposure to boy's/men's cricket accelerated skill development, with adaptability crucial for both groups' expert performance. Unlike modern skill development methods, training design often uses functional games or misaligned task deconstruction. Aims for discrete stages of the pathway could have been more transparent for both cohorts, potentially limiting their value. Coaches perceived fluid transitions between stages, unlike players who described rigidity.	Coaches are advised to examine the essential elements of task design to achieve distinct representativeness and enhance skill development in amateur cricketers. The increase in investment, contracts, and player support for female cricketers has created a skill gap between pathway stages, which must be addressed. Improving coaching practices and support at amateur cricket levels can help close the skill gap and develop the next generation of elite female cricketers.
Lascu et al. (2022c)	Australia, Premier level (n=18)	The programme was designed to promote skill development and was performed over five weeks with two amateur female cricket teams to provide a framework for community coaches at the foundation stage of cricket. Year of study not reported.	Outcomes for skilled actions and cognitions were measured through a combination of qualitative and quantitative methods to evaluate skill development throughout a five-week intervention.	Female only. Heterogenous. Good.	Six of ten batters and seven of eight bowlers exhibited increases in skill development ranging between 7–49%. Batting and bowling behaviour changes improved substantially between moderately and extensively designed sessions. Batters' thoughts shifted from their skill execution to objectives, while bowlers focused on their opponent's execution. Moderate to extensive RLD promotes skill development in amateur cricketers, making it a viable option for coach education and training design at the foundation level of cricket.	Coaches are advised to examine the essential elements of task design to achieve distinct representativeness and enhance skill development in amateur cricketers.
Liang et al. (2023)	UK, Club and county level (n=18)	The study aim to determine (1) whether there is a speed-accuracy trade-off during a fielding task, where speed refers to the time taken from the start of the approach until ball-target contact, if so, (2) determine where in the sequence of events the trade-off occurs, and (3) determine whether there exists a difference in strategy between experienced male and female cricketers. Year of study not reported.	Players were required to run to a stationary ball and throw it to the centre of a target to run out a virtual batter.	Male and female. Heterogenous. Good.	Eighteen female cricket players (age: 20.3 ± 1.2 years, height: 168.4 ± 6.4 cm, weight: 67.2 ± 8.2 kg, experience: 10.6 ± 2.8 years) were recruited. Female participants threw with a peak velocity of 24.2 ± 3.3 ms−1. Males were significantly faster than females (3.00 ± 0.26 s) in the speed condition. Error score was significantly lower in accuracy, with males scoring typically lower than females. Participants were faster to reach the ball in the speed condition (1.86 ± 0.18 s vs. 2.07 ± 0.22 s), with males being faster than females in both conditions. A significant interaction showed that females spent less time with the ball in the speed condition (0.69 ± 0.11 s vs. 0.79 ± 0.11 s) ($t_{1,17} = 13.33$, $p = .001$, $\eta^2 = 0.28$). Males threw the ball faster than females, as shown by a	Both groups of cricketers employed a similar strategy to minimize the overall task duration; however, distinct gender characteristics were observed in their approach and throwing speed. The shift from prioritizing accuracy to speed led to a modification in the throwing technique for 31% of the participants. However, additional research is needed to understand the factors that prompted this change.

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
					significant main effect. In the vertical score, females hit the target higher (0.63 ± 0.60) than males in the speed condition ($t1,34 = 6.88$, $p = .013$, $\eta2 = 0.17$). In addition, females hit the target higher above its centre in the speed condition compared to accuracy ($t1,17 = 8.30$, $p = .007$, $\eta2 = 0.20$).	
Morgan et al. (2023)	Australia, Junior level (n=20)	Aim of this current study was to assess the feasibility of this programme. Specifically, programme feasibility was evaluated with reference to (1) recruitment capability, (2) fidelity of programme delivery, (3) attendance, (4) compliance, (5) programme satisfaction, (6) retention and (7) preliminary efficacy of the programme on cricket-specific outcomes. 2020-2021	The Daughters and Dads Cricket programme is a sport-adapted version of the Daughters and Dads Active and Empowered programme.	Female only. Homogenous. Good.	Recruitment (n = 34 dads), fidelity (98% education, 100% practical), attendance (88%), satisfaction (fathers: 4.6 of 5, daughters: 4.8 of 5), and retention (97%) exceeded feasibility benchmarks. Home program compliance was below the benchmark (64%). Medium-to-large effect size changes in 11 of 13 daughters' cricket skill proficiency outcomes confirmed preliminary efficacy. Positive findings were found in daughters' enjoyment, intention to play, and long-term retention in cricket.	Daughters and Dads Cricket' is the first programme internationally to target fathers as agents of change to enhance girls' cricket skill proficiency and cricket participation.
Coordination/proprioception (n=2)						
Paul (2017)	India, Club level (n=25)	The study aimed to analyse the hand reaction time and hand eye coordination among female cricket and handball players. 2017	Digital Reaction Time Tester was used to assess the hand reaction time of selected female players. For measuring hand-eye coordination, a Ball transfer test was adopted.	Female only. Homogenous. Fair.	Results found that female cricket players have slower auditory reaction time and faster visual reaction time than female handball players. Female cricket players have poor hand-eye coordination as compared to female handball players.	-
Reddu (2016b)	India, Club levels (n=20)	The study aims to compare the rhythmic ability of one of the coordinative variables of male and female cricket players at different levels. Year of study not reported.	Only one coordinative ability variable, such as rhythmic ability, are considered. To establish the effect of the circuit training and Interval training vascular endurance	Male and female. Homogenous. Poor.	The mean rhythmic ability score for female players with low performance was 9.73. The hypothesis was rejected at a significance level of 0.05, indicating a significant difference in rhythmic ability between male and female low-performing students. The mean rhythmic ability score for female high-performance players was 9.29. The standard deviation of female high-performance players was 0.31.	-
Aerobic and anaerobic fitness (n=4)						
Boby and Badhan (2023)	Bangladesh, Division level (n=60)	This study aimed to evaluate the level 1 Yo-Yo Intermittent Recovery Test results for the aerobic endurance fitness of female cricket bowlers and batters. Year of study not reported.	Yo-Yo Intermittent Recovery Test Level 1 (YYIRTL1)	Female only. Homogenous. Fair.	There were significant differences between batters and bowlers in total covered distance, VO_2 max and Levels achieved of YYIRT Level-1. It was concluded that bowlers had scored better in Level Achieved than the batters. The results also	-

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
					revealed that bowlers had performed better in total distance covered as well as in VO_2 max as compared to the batters.	
Pankajbhai and Shantilal (2015)	India, Club level (n=20)	To check or assess the speed of running in female cricket players by before and after core stability training. 2015	Core was assessed using lateral bridge, torso flexors test, extensor endurance. Speed is measured by 4x10shuttle run test and T-test for agility before and after given 2 weeks of core stability training.	Female only. Heterogenous. Fair.	The average value of the pre-4x10 shuttle run test was 30.1885, while the average value of the post-4x10 shuttle run test was 25.8530. The mean value of pre-T-test for agility was 18.1205, while the mean value of post post-T-test for agility was 15.2025. There is a significant difference between the pre-and post-data. The study found that a 2-week core muscle exercise training program resulted in improved running speed.	A two-week core stability training program was found to enhance running performance in female cricket players.
Raj and Sudheer (2018)	India, Club level (n=30)	This study aims to evaluate the impact of aerobic dance and yoga on specific motor abilities in intercollegiate female cricket players. Year of study not reported.	Group A was designated as the Aerobic Dance group and received training for 6 weeks. The training sessions occurred on three specific days (Monday, Wednesday, and Friday) each week, taking place in the early morning from 6 am to 7 am. Group B was classified as a Yoga group and received training three times a week (on Tuesday, Thursday, and Saturday) from 6 am to 7 am for a duration of six weeks.	Female only. Homogenous. Good.	The study found that both Aerobic Dance and Yoga significantly improved explosive power, flexibility, and endurance. The study compared Group A (Aerobic Dance) with a control group and found significant improvements in explosive power, flexibility, and endurance because of aerobic dance. The experimental group B, which practised Yoga, was compared to the control group C. The results showed a significant improvement in flexibility because of practising Yoga. The study found that the experimental group that participated in aerobic dance showed a greater improvement in explosive power compared to the group that practised Yoga.	-
Sandhu and Singh (2018)	India, level of play not specified (n=30)	The present study aimed to assess the Yo-Yo Intermittent Recovery Test Level 1 (YYIRTL1) between Punjab female cricketers, India and Dhaka female cricketers, Bangladesh. Year of study not reported.	Yo-Yo Intermittent Recovery Test Level 1 (YYIRTL1)	Female only. Heterogenous. Fair.	The mean scores for the Yo-Yo Intermittent Recovery Test Level 1 (YYIRTL1) for female cricketers from Dhaka, Bangladesh, and Punjab, India, were 15.2 and 14.5, respectively, while the corresponding standard deviations (SD) were 0.67 and 0.73. The observed value of t (2.61) is greater than the critical value of t at the 95% probability level (1.761). The results show a significant difference in the Yo-Yo Intermittent Recovery Test Level 1 scores between female cricketers from Dhaka, Bangladesh, and Punjab, India.	-

Supplementary Table 3-8. Study characteristics of physical characteristics studies included in the scoping review (n=8)

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
Anthropometrics (n=6)						
Koley and Kashyap (2010b)	India, Club level (n=56)	The purpose of this study was two-fold, firstly, to evaluate the anthropometric profile of Indian inter-university female cricketers and, secondly, to find correlations among these anthropometric characteristics. Year of study not reported.	Anthropometrical assessment using fifteen anthropometric characteristics: height, weight, biceps skinfold, triceps skinfold, subscapular skinfold, suprailiac skinfold, calf skinfold, upper arm circumference, forearm circumference, gip circumference, thigh circumference, calf circumference, abdominal circumference, humerus bi-epicondylar diameter and femur bi-epicondylar diameter were measured on each subject following standard techniques	Female only. Homogeneity. Good.	The present study's findings indicated significant differences ($p \leq .05$) between Indian inter-university female cricketers and controls in subscapular skinfold, suprailiac skinfold, calf skinfold and thigh circumference. Weight has significantly positive correlations ($p \leq .01$) with all the variables studied (except height and biceps skinfold). Significant positive correlations ($p \leq .05$) were found with all the variables studied except height and humerus bi-epicondylar diameter for all five skinfold measurements. Similarly, for all the six circumferential measurements, significantly positive correlations ($p \leq .05$) were noted with all the variables studied except for height.	The data presented in the present study has immense practical application and should be helpful in future investigations on player selection, talent identification in cricket, and training program development.
Singh (2016a)	India, Club level (n=35)	Assessment of selected anthropometric characteristics of female Cricket players. To determine the correlation between selected anthropometric variables and performance score. Year of study not reported.	Anthropometric measurements included weight, standing height, sitting height, leg length, upper leg length, arm length, and lower leg length. Three experts assessed the selected female cricket players' performance using a weighing scale, anthropometric rod, steel tape, and skin fold calliper.	Female only. Homogenous. Fair.	Leg, upper, and arm length were significantly related to women's cricket performance and may predict performance. Upper leg length did not predict women's cricket performance so that it may be dismissed. Instead of studying each independent variable, the study's variables may be considered in combination to predict women's cricket players' performance better.	-
Stuelcken et al. (2007)	Australia, National level (n=26)	This study aimed to describe the current anthropometric profiles of elite Australian female and male cricket fast bowlers and establish a set of reference values useful for future investigations on player selection, talent identification, and training programme development. Year of study not reported.	All anthropometric measures were taken by an experienced Level 2 certified anthropometrist with the International Society for the Advancement of Kinanthropometry following the procedures described by Norton and colleagues (1996). Corrected girths were calculated at the sites where the skinfold and girth measurements coincided (upper arm, thigh, and	Male and female. Homogenous. Good.	Male bowlers exhibited greater length, breadth, and girth measurements than their female counterparts. Sex differences in proportionality were observed, with only male bowlers displaying characteristics that could be classified as "large" in relation to height. Female bowlers exhibited a significantly higher sum of seven skinfolds, greater endomorph, and lower mesomorph than male bowlers.	-

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
			calf) using a formula proposed initially by Jelliffe and Jelliffe (1969).			
Tahoor and Koley (2019)	India, State level (n=79)	Investigate the anthropometric profile of female cricketers of Maharashtra and Punjab state in India and to search any correlations of selected anthropometric variables with performance tests. Year of study not reported.	Seven anthropometric variables, such as, height, weight, BMI, hand length, hand breadth, upper arm circumference and percent body fat, and three physical fitness tests i.e. dominant handgrip strength, non-dominant handgrip strength and Illinois agility test were measured on each subject using standard technique.	Female only. Homogenous. Fair.	The non-dominant handgrip strength, upper arm circumference, and percentage body fat of Maharashtra and Punjab cricketers differed significantly. Positive correlations were found between dominant handgrip strength, non-dominant handgrip, height, BMI, hand length, and percentage lean body mass in pooled cricketers. The non-dominant handgrip strength was positively correlated with height, weight, BMI, hand length, and percentage lean body mass and negatively correlated with the Illinois agility test in pooled cricket. A significant negative correlation was found between the Illinois agility test and the percentage of lean body mass in pooled cricketers.	The study's findings have significant practical implications for identifying talent in female cricketers based on their specific anthropometric parameters. Optimising training programs tailored to the specific requirements of cricket can be beneficial for preventing player injuries.
Thenmozhi and Indira (2019)	India, All levels (n=120)	The purpose was to analyse the selected bio-motor variables among professional and non-professional female cricket players. Year of study not reported.	Speed was assessed by 50-meter runs, and shuttle runs assessed agility.	Female only. Heterogeneity. Fair.	The result reveals a significant difference on speed and agility among professional and non-professional female cricket players. The professional players performed better performance than the non-professional players on speed and agility.	-
Mandoli and Sharma (2018)	India, Domestic level (n=20)	The purpose of the study was to compare the physiological and anthropometric variables, i.e. Vital Capacity (VC), Resting pulse rate (RPR), Leg length, and Body fat% between the batsmen and bowlers in cricket and to develop criteria for classifying female cricket players into batsmen and bowlers by using discriminant analysis on the basis of physiological and anthropometric variables. 2018	Vital capacity (VC) were measured in litres, Resting pulse rate (RPR) were measured for 30 sec. count, Leg Length were measured in cm, Body fat % were measured in kg.	Female only. Homogeneity. Fair.	There were notable physiological and anthropometric differences observed between batters and bowlers, specifically in variables, i.e. VC, RPR, Leg length, and Body fat %. Additionally, there was a significant difference in the mean scores of the four variables between the two groups. The mean value is higher in bowlers. Conversely, the mean value is higher in batters for leg length.	The study's findings indicate that coaches and fitness trainers should focus on physiological and anthropometric variables starting from fundamental stages.

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
Physiology (n=2)						
Dwivedi (2022)	India, Junior level (n=30)	This study aimed to compare the physiological variables of qualified and not qualified teams of U-19 girls' cricket divisional tournament of M.P. Year of study not reported.	Hand grip strength test from dynamometer, forced vital capacity test by a spirometer, oxygen saturation and heart rate by a pulse oximeter.	Female only. Homogeneity. Good.	The statistical analysis revealed a significant difference in forced vital capacity between qualified and not qualified teams, possibly due to the superior lung capacity of high-level players. However, no significant differences were found in left-hand grip, right-hand grip, and SPO2 between the two groups. The data suggests that to achieve high performance in cricket, physical fitness, specifically lung capacity, is equally important as skill.	-
Negi and Pritam (2012)	India, All levels, (n=260)	To ascertain whether there is any significant difference in physiological variables i.e. blood pressure (diastolic and systolic), pulse rate, breath holding and respiratory rate among the female cricket players at different levels of participation. 2008-2011	Blood pressure (both) with stethoscope, sphygmomanometer. Pulse rate with digital pulse rate monitor. Respiratory rate and breath holding with Swiss standard stopwatch.	Female only. Heterogeneity. Good.	The findings show that Group I players (Interuniversity and national level) are better in blood pressure diastolic, pulse rate, respiratory rate and breath-holding from Group II (inter-college and state level) female cricket players.	-

1 repetition maximum (1RM), body fat composition (BFC), body mass index (BMI), ball release speed (BRS), countermovement jump (CMJ), Cohen's d (d), functional fatiguing contraction (FFC), global positioning system (GPS), isometric mid-thigh pull (IMTP), key performance indicator (KPI), left-handed (LHD), lower back pain (LBP), rating of perceived recovery (RPR), right-handed (RHD), session rating of perceived exertion (sRPE), standard deviation (SD), twenty20 cricket (T20), United Kingdom (UK), United States of America (USA), vector coding (VC), VO2 max (VO2max), Yo-Yo intermittent recovery test (YYIRT).

Supplementary Table 3-9. Study characteristics of psychology studies included in the scoping review (n=36)

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
Acharya and Subudhi (2023)	India, National level (n=71)	The purpose of the present study was to compare the group/team cohesion among the female cricket players of different teams in the northern zone of India. The subordinate purpose of this study was to investigate the most dominating group cohesion factors among the groups. Year of study not reported.	Group Environment Questionnaire is composed of eighteen items that measure the four-team cohesion dimensions, and they are – Group integration-social (GI-S), Group integration-task (GI-T), Individual attraction to the –group (ATG-S), Individual attraction to the group task (ATG-T). Each item is anchored to an eight-point Likert scale ranging from 1= strongly disagree to 8= strongly agree.	Female only. Homogeneity. Fair.	It was found that in attraction towards group-Social and Group Integration-Social, there was no significant difference found among the groups, as the calculated 'F' Value for ATG-S and GI-S (2.02 & 2.68 respectively) are smaller than the tabulated value (2.74) at 3.66 degrees of freedom at0.05 level of significance. In most of the factors of the GEQ, female cricketers from Delhi scored better than the other teams.	This article highlights the importance of team-building and encourages further research and the development of new frameworks on team dynamics.
Ahmad (2016)	India, State level (n=50)	Compare male and female cricket players on their levels of sports competitive anxiety. Year of study not reported.	The data collection tool used to measure sports anxiety was the Sports Competition Anxiety Test (SCAT) developed by Renier Martin. Data on the sports competition anxiety of male and female cricket players was compared using an independent t-test, the results were analysed, and interpretations were drawn.	Male and female. Homogenous. Fair.	Statistically significant differences were observed in Sports competition anxiety between male and female cricket players. The mean scores indicate that female cricket players experience higher levels of sports competition anxiety compared to male cricket players. In this study, researchers observed that male cricket players exhibited higher levels of sports competition anxiety compared to their female counterparts. Female cricket players experience higher levels of sports-related competitive anxiety compared to their male counterparts. The anxiety experienced by male and female cricket players during sports competitions differs significantly and plays a crucial role in their success both on the field and in society.	Understanding the psychological variables influencing player performance is crucial for optimal results.
Andrews et al. (2022)	Australia, National level (n=3)	In an Australian context, provide insight into coaches' and players' understandings of shared athlete leadership in their cricket team. A second aim was to examine to what extent coaches' and players' expectations of	Interpretative phenomenological analysis (IPA) approach was used to explore the participants' experiences and elicit their perceptions of shared athlete leadership in their cricket team	Male and female. Homogenous. Fair.	The findings indicate that the coach and players prioritise the captain's social leadership skills over their task leadership skills. Additionally, the captain relies on informal athlete leaders for tactical guidance. However, there were varying expectations concerning the role of athlete leaders. The coach anticipated athlete leaders would convey his message to the team, but players desired athlete leaders who fostered communication between players and the coach.	This study's findings offer an additional understanding of the distinctions and similarities in how coaches and players perceive shared athlete leadership. This study contributes to shared athlete leadership by emphasizing the distinct characteristics of captains compared to other athlete leaders. Coaches can utilise these differences to effectively

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
		their athlete leaders align. Year of study not reported.				identify and cultivate athlete leaders who are recognised as leaders by both themselves and their teammates.
Anshuman (2014)	India, Club level (n=19)	This study aimed to compare the motivation and goal orientation of male and female collegiate-level cricketers. It was hypothesized that there would be a significant difference in the motivation and goal orientation between male and female collegiate level cricketers. Year of study not reported.	The measuring instruments used for the study were the Sport Motivation Scale (SMS-28) (Pelletier et. al, 1995) and Task and Ego Orientation in Sport Questionnaire (Duda & Whitehead, 1998). SMS tested three motivation factors: intrinsic motivation, extrinsic motivation and motivation and TESQ tested task and ego orientation of an individual.	Male and female. Homogenous. Poor.	The results showed a significant difference between the two groups. The calculated t-values for motivation and ego orientation were 2.342 and -2.217, respectively, with 36 degrees of freedom. These values were more significant than the tabulated value of 2.021 at 40 degrees of freedom (the next higher value was used since the exact value for 36 degrees of freedom was not available).	-
Bhalla (2018)	India, National and club level (n=30)	The objectives of the study are to assess phobic disorders in female boxers and female cricket players. Year of study not reported.	Jodhpur Multiphasic Personality Inventory prepared by Joshi and Malik, 1981	Female only. Heterogenous. Fair.	A significant difference in the magnitude of phobic disorder was observed between boxers and cricket players. The reported t-value of 3.43 ($p < .01$) confirms that the magnitude of phobic disorder was significantly higher in boxers (M = 12.90) compared to cricket players (M = 8.95).	-
Bull (1995)	UK, National level, sample size not specified.	This paper documents a 5-year sport psychology consultancy program with the England Women's Cricket Team. Year of study not reported.	This paper documents a 5-year sport psychology consultancy program with the England Women's Cricket Team. The paper describes the method and content of sport psychology service provided and distinguishes between phases of delivery.	Female only. Homogenous. Poor.	Based on a 5-year experience, the following recommendations for consultants delivering extended sports psychology services to international teams are recommended: 1. Experience the sport's culture. Expand the role to include general training and preparation and become part of the coaching team. 2. Be cautious with psychological testing. Check the value of testing before implementation and consider performance profiling (Butler & Hardy, 1992) as an alternative when feasible. 3. Offer many group discussions. Promote an open and honest exchange of opinions. Maintain regular role reviews and clarifications. 4. Prioritise building solid relationships with coaching and management staff. Inform them about the topics to discuss with athletes. 5. Encourage athletes to provide feedback on the sport psychology program. Generate feedback through various methods, such as evaluation forms, group discussions, formal interviews, and informal meetings. 6. Attend competitions to observe and then provide services. Prepare to feel insignificant, but use teachable moments effectively. 7. Review publications by other experienced professionals before and during consultation. In 1991, Partington and Orlick analysed the best consultancy experiences of Olympic consultants, which is a valuable reference.	

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
Bullock et al. (2020a)	UK, All levels (n=65)	The purpose of this study was to i) evaluate HRQoL (physical and mental components) and flourishing in recreational and elite and current and former cricketers; ii) determine the effect of resilience, playing standard, and playing status on HRQoL and flourishing in cricketers. 2017	Developed questionnaire was designed to evaluate five aspects of health and wellbeing: i. cricket-related injury; ii. joint pain and osteoarthritis; iii. General health and disease prevalence; iv. physical activity; v. resilience, quality of life and flourishing (the focus of this study).	Male and female. Heterogeneity. Good.	The average age of female cricket players was 43.8 years, with a standard deviation of 13.9 years. The median BMI was 24.4, with an interquartile range of 21.4 to 27.4. The median number of female cricket seasons was 9, with an interquartile range of 4 to 14 seasons. The median PCS score for females was 51.0, with an interquartile range of 46.0 to 58.3. The median MCS score was 52.4, with an interquartile range of 46.6 to 58.3. The median flourishing score was 48, with an interquartile range of 44 to 52. There were no significant differences in PCS, MCS, or flourishing scores between males and females. The relationships between resilience, playing standard, playing status, HRQoL and flourishing were similar in male cricketers compared to all cricketers.	Greater flourishing is positively correlated with increased cricket participation and a higher standard of play. The study found that engaging in cricket was linked to improved physical well-being.
Chaturvedi et al. (2013)	India, National level (n=30)	A comparative study was conducted on competitive behaviour and team cohesion between male and female Cricket National players of Madhya Pradesh. Year of study not reported.	Competitive behaviour questionnaire developed by Frank Tyson & Group Environment Questionnaire (GEQ)	Male and female. Homogenous. Fair.	No significant differences were found in competitive behaviour between male and female cricketers. Male and female cricketers showed no significant differences in group attraction, task integration, social integration, and task cohesion. Both male and female national cricketers exhibited average competitive behaviour and team cohesion.	The study suggests that team cohesion and competitive behaviour significantly improve player performance.
Ely et al. (2023)	UK (England), National level (n=36)	In the present study, we sought to identify the impact of bio-bubbles on the mental health of those residing within them and then explore the underlying mechanism of any such impact. 2020-2021	Anxiety - Generalized Anxiety Disorder Scale, Depression - Patient Health Questionnaire, Wellbeing - 5-item World Health Organization Index, Basic psychological need satisfaction and frustration - Basic Psychological Need Satisfaction and Frustration Scale	Male and female. Heterogeneity. Good.	The negative impact of being in the bubble on mental health was found to be more pronounced for women compared to men. There were significant differences in well-being based on sex and bubble status, with women experiencing lower WHO-5 scores (M = 14.41, SD = 5.01 compared to men, and higher scores reported outside the bubble compared to inside.	Women showed more significant increases in depression and anxiety within the bubbles, highlighting the need for careful preparation and monitoring of isolating environments.
Fowlie et al. (2021)	Australia, Junior level (n=20)	In this qualitative study, we investigated the barriers to adolescent female participation in cricket in a regional city in Victoria, Australia. Year of study not reported.	Interviews based on the socio-ecological model. Demographics questionnaire.	Female only. Heterogeneity. Good	Participants highlighted barriers to cricket participation, such as a lack of confidence and limited career advancement for female cricketers. Female-only tournaments and strategies to reduce obstacles for adolescent girls were suggested. Critical factors in engaging teens in cricket include skill development, confidence-building through exercise, and dedicated programs. Competition enhances skills and fosters friendships, with women-only events offering accessibility. Inclusivity, from community to high-level cricket, requires recognising female achievements. Decisions at various levels should prioritise qualified coaches, female-only teams,	To promote adolescent female participation in cricket, it is suggested to focus on skill development. This can help build confidence and enable them to compete effectively. Design a women's cricket tournament focusing on enhancing skills and fostering friendships.

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
					player pathways, and supportive club environments for an inclusive sports culture.	
Gamit (2013)	India, National level (n=20)	The purpose of the study was to compare the level of anxiety between male and female national cricketers of Gujarat. Year of study not reported.	Sports Competition Anxiety Test developed by Martens (1977)	Male and female. Homogenous. Poor.	Results of the study revealed no significant difference between male and female national cricketers of Gujarat regarding sports competition anxiety.	-
Gill (2018)	India, District level (n=15)	Comparative study of aggressive behaviour between male and female cricket players of Bhiwani district in Haryana. Year of study not reported.	Aggression behaviour was assessed using self-developed aggression tests.	Male and female. Homogenous. Poor.	A significant difference was found between the mean scores of male and female cricket players of Bhiwani. Female cricket players were significantly more aggressive than the male cricket players of Bhiwani district in Haryana.	-
Gurjar and Kakran (2020)	India, Club level (n=60)	To assess the level of self-confidence of female cricket players from different states of North India. To compare the self-confidence of female cricket players from different states of North India. Year of study not reported.	Standard Hardy and Nelson (1992) questionnaire for self-confidence.	Female only. Homogenous. Fair.	The findings showed that Haryana state's female cricket players had greater self-confidence than those from Punjab and Delhi. For cricket players from Delhi, Punjab, and Haryana, the mean and standard deviation values for self-confidence are 19.83±1.33, 17.65±1.89, and 20.73±1.44, respectively. The self-confidence of female cricket players from Delhi and Punjab (1.89*) and Delhi and Haryana (1.99*) differs significantly, while that of cricket players from Punjab and Haryana (0.67) does not significantly differ. There are notable differences in the self-confidence of female university cricket players from various North Indian states.	-
Jahangir and Manzoor (2019)	Pakistan, National, domestic and junior levels (n=35)	The objective of this study is to explore different perspectives regarding sports women in sports activities, and it also aims to analyse critically the misconceptions regarding women sports. Year of study not reported.	The researcher collected data through interview schedules from 210 sports women residing in different places of Pakistan.	Female only. Heterogenous. Poor.	Case study, only one report: Sana Mir (Cricketer). At the time of her introduction to cricket, there needed to be more adequate facilities for female players in educational institutions and other locations. During the 1990s, there were few female cricket clubs. As a result, she acquired cricket skills by playing in the streets, eventually attaining her current status. She has been balancing her education and cricket, striving to succeed. With the support of her father, she pursued a cricket career. She also attributes her success to her family, particularly her father, whose support enabled her achievements. The player also discussed the support and assistance provided by her mother during challenging moments. Furthermore, the evident outcome is that she holds the position of captain of the Pakistan Cricket team.	There must be a separate subject for sports at educational levels, where teachers can explain the benefits of sports for girls' physical and mental health. There must be specific spaces or infrastructures for women to have various curricular and extra-curricular activities for their physical development. The State should encourage and give incentives/benefits to girls and women to participate in sports activities.
Khan et al. (2017)	Pakistan, National level (n=53)	The present study aimed to explore the relationship between Mental Toughness and Athletic Performance of corporate cricket players of	Questionnaires of Mental Toughness Inventory (MTI) and the Coach Athlete Rating Scale of Athletic Performance	Male and female. Homogenous. Fair.	A significant difference in mean mental toughness test scores was observed between males (n=123, M=30.3089, SD=2.22920) and females (n=53, M=26.9434, SD=3.89978), t(67.107)=5.882. The study also investigated the characteristics of mental toughness. The gender analysis indicated a notable male presence. Males generally	Improving their competitive exposure is imperative to enhance female athletes' mental resilience. It is advisable to engage certified coaches and psychologists to support the

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
		Pakistan on sex bases. 2016-2017	(Coach-Athlete Rating Scale of Athletic Performance) were used to collect the data form the respondents.		exhibit higher self-efficacy (M = 4.20) than females (M = 3.47) when predicting future outcomes. The mental self-concept scores of males (M = 4.57) and females (M = 4.19) were examined. The average score for males in the study was 13.04, compared to 11.68 for females. The familiarity of the participants with the task was also considered. Female cricket players exhibit a lower mean score (M = 7.60) than female soccer players (M = 8.50).	psychological growth of male and female cricket players. Sports organisations should implement national-level and grassroots psychological development programs to enhance cricket players' cognitive and physical capacities.
Kakran and Gurjar (2020)	India, Domestic and junior levels (n=60)	This study aims to evaluate the mental toughness of cricketers across various age groups. Year of study not reported.	Mental Toughness Questionnaire" designed by Dr. Goldberg.	Female only. Heterogenous. Fair.	The study demonstrates the use of descriptive analysis to examine the mental toughness of cricketers in different age groups (9-12, 13-16, and 17-20). The mean and standard deviation values for mental toughness are 19.87±3.061, 20.23±4.117, and 17.44±3.004, respectively. The analysis reveals a significant difference in mental toughness among the various age groups, with a significant value of 8.84 at a significance level of 0.05.	-
Kohli (2015)	India, level of play and sample size not specified.	Letter to editor addressing if female cricketers have different psychosocial issues compared to males? Year of study not reported.	N/A (opinion paper)	Female only. Homogenous. Poor.	Women's cricket has evolved significantly, focussing on the psychosocial development of female athletes. Power dynamics in sports and broader gender relations are shifting, with increased opportunities and promotion for female players. While power inequalities in cricket have decreased, complete equalisation is yet to be achieved. The rise of women's cricket is attributed to moral, historical, financial, and organisational factors. Female athletes, in general, demonstrate superior skill development, play negotiation, and finesse compared to males.	
Kumar (2013)	India, Club level (n=60)	Compare aggression in female cricket players of different levels of participation. 2011-2012	Sports Aggression The inventory was constructed and standardized by Prof. Anand Kumar Shrivastava and Prem Shankar Shukla.	Female only. Homogenous. Poor.	The results showed a significant difference in aggression levels between female cricket players participating in the All-India Intervarsity and West Zone Intervarsity tournaments.	-
Kumar and Gill (2019)	India, Club level (n=40)	Study of competitive anxiety among high and low achiever female cricket players of Haryana. Year of study not reported.	Players Sport Competition Anxiety Test, developed by Martens et al. (1990)	Female only. Homogenous. Poor.	The team that got the 1st and 2nd position in women's inter-college was considered high achievers, and 3rd and 4th position teams were considered low achievers. The high position holders had values of 17.80 and 2.32, while the low position holders had mean and standard deviation values of 16.06 and 1.52, respectively. The study found that high-position holders had higher mean scores than low-position holders, suggesting that high-position holders experience more anxiety during competition. There was no significant difference in competitive anxiety levels between individuals in high positions and those in low positions. No significant difference was found in sports competitive anxiety between high-position holders and low-	-

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
					position holder female cricket players. Both groups showed optimal levels of sports competitive anxiety.	
Marlow (2002)	UK (England), National level, sample size not specified.	The aim is to elevate athletes' perspectives in sport psychology research, promote understanding of their experiences and behaviours, define the adherence process, promote research on sport-specific populations, and promote reflection and debate among the applied sports science profession on athlete support. 1996-1997	Various interpretive methods were used to understand players' training adherence perspectives. This included direct experience, documentary evidence review, and player and sport science support staff interviews.	Female only. Homogenous. Fair.	Unique perspectives shape players' and sporting bodies' needs for sports science services. Sports scientists should adapt their approach accordingly, integrating it into training programs from athletes' viewpoints. The role of sports scientists needs a review, emphasizing a rethinking of consultancy philosophy and skills to support athletes better. This includes raising athletes' awareness of how their holistic context influences their needs and aspirations. Evaluating working conditions and optimising contracts for athlete-centred delivery is vital. Enhancing performance requires collaboration between sports scientists and sporting bodies. The structure of sports science needs examination, emphasising interdisciplinary collaboration among physiologists while recognising their roles.	
Navaneethan and Soundara Rajan (2009)	India, State, club and junior levels (n=70)	The purpose of this study was to examine the differences in goal orientation between Indian and Australian female cricketers. Year of study is not reported.	Task and Ego Orientation in Sport Questionnaire	Female only. Heterogenous. Poor.	The study found significant differences in task and ego orientation among players from the two countries. The results suggest that Australian players exhibited higher task orientation than Indian players.	Australian players exhibit a higher task orientation level than their Indian counterparts. This study provides insights into the goal-orientation approaches of Indian women's cricket. Hence, further research is required to apply theoretical principles to practical procedures in the field.
Rubab and Iqbal (2021)	Pakistan, National, state, club and junior levels (n=200)	The study investigated the correlation between extrinsic and intrinsic motivation among Pakistan's elite and non-elite female cricketers. Further, the impact of motivation on sports performance was also analysed. Year of study not reported.	The Sports Motivation Scale (Palletier et al., 1995) and Athlete Subjective Performance Scale (Nahum et al., 2016) were used in the study.	Female only. Heterogenous. Good.	A strong positive correlation was found between extrinsic and intrinsic motivation in elite and non-elite individuals ($r=0.981$, $p<0.001$ for elite; $r=0.991$, $p<0.001$ for non-elite). The study found a strong positive correlation between intrinsic motivation to know and external regulation among elite and non-elite female cricketers. For elite cricketers, the correlation coefficient was 0.987 ($p<0.001$), while for non-elite cricketers it was 1.000^{**} ($p<0.001$). The study found a significant impact of motivation on sports performance in elite and non-elite respondents ($R2=0.117$, $p<0.001$ for elite; $R2=0.118$, $p<0.001$ for non-elite). Motivation is crucial role in sports involvement and attaining of an athlete's optimal performance.	Sports organisations and educational institutions should offer professional psychological support to improve sports motivation. This support should consider athletes' psychological needs, including appreciation, incentives, security, and support.
Rubab and Iqbal (2022)	Pakistan, National, college, school, or club level (n=200)	To identify the impact of external rewards on the intrinsic motivation of elite and non-elite female cricketers of Pakistan. Year of study not reported.	External rewards: The study used the Effort & Reward Scale (IK-Park, 2021). Intrinsic Motivation: It was assessed using the	Female only. Heterogeneity. Good.	The study found that external rewards positively affect the intrinsic motivation of elite individuals ($R2= 0.408$, $p= 0.000c$). However, no impact of external rewards was observed on the intrinsic motivation of non-elite individuals ($R2= 0.003$, $p= 0.604c$). Motivation is crucial role in sports engagement and attaining of an athlete's optimal performance. External rewards can enhance intrinsic motivation. The study suggests that women's cricket organisations should focus on	-

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
			Sports Motivation Scale (Pelletier et al., 1995).		improving sports motivation by addressing the psychological needs of athletes, including recognition, rewards, security, and support.	
Russell (2004)	UK, All levels (n=10)	This study investigated the development of body satisfaction among female rugby players, cricketers, and netballers. This study also assessed the impact of sports participation on athletic and "feminine" identity. Year of study not reported.	Respondents took part in a semi-structured interview based on their experience of playing sports and the impact the sport had made on their perceptions of their bodies. The four sections of the interview covered demographics, body satisfaction, appearance, and personal experiences.	Female only. Heterogenous. Fair.	In a particular scenario, female cricket players strongly rejected any association with homosexuality by openly expressing their "feminine" qualities. This appeal to societal expectations of appearance may be seen as an effort to avoid being labelled as a lesbian. Female cricketers report that there are instances where individuals may present themselves as a potential sexual target for men within the same club. In social settings, women's body satisfaction decreases, and their perceptions of their bodies change. This is due to the pressure they feel to conform to societal standards of physical attractiveness, particularly about heterosexual norms.	The study found that individuals expressed fear of being seen as lesbian, as well as a belief that being concerned about one's body is natural.
Sailan et al. (2016)	Malaysia, National level (n=21)	This research aims to identify the psychological profile of Malaysian female cricket athletes. Year of study not reported.	Sports Mental Toughness Questionnaire (SMTQ), the Sports Competition Anxiety Test, Leadership Scale for Sports (LSS).	Female only. Homogenous. Good.	The findings indicate that female cricket athletes in Malaysia have limited mental endurance. Motivation is the key determinant of mental endurance. The study found that athletes experience a moderate level of anxiety. Training and orders were identified as the primary leadership qualities among athletes, while the autocratic dimension was found to be the least prominent. Coaches commonly utilise positive feedback as a significant leadership quality, while the authoritarian dimension is least frequently employed.	This study offers valuable insights into sports, particularly for coaches and individuals involved in sports development from a psychological perspective, which can impact athletes' performance.
Sandhu et al. (2017)	India, Club level (n=50)	The present study aimed to assess the Anxiety and Achievement Motivation in All India Intervarsity female cricketers. Year of study not reported.	State and Trait Anxiety (Chattopadhyay, Mallick, and Spielberger (1986)). Achievement Motivation, SAMT (Kamlesh (1987))	Female only. Homogenous. Fair.	Winner and loser groups had mean State Anxiety values of 44.75 and 46.46, respectively, with SDs of ±5.02 and ±4.32. T's 95% probability level critical value (1.711) is higher than its observed value (1.264). The data showed no significant difference between winner and loser groups for State Anxiety. Winner and loser groups had mean Trait Anxiety values of 47.29 and 49.46, respectively, with SDs of ±4.30 and ±3.55. The critical value of t at 95% probability is lower (1.711) than the observed value (1.801). The Trait Anxiety variable showed significant differences between winner and loser groups. Winner and loser groups had mean Achievement Motivation values of 30.21 and 27.50, respectively, with SDs of ±1.84 and ±3.34. The critical t value at 95% probability is 1.711, lower than the observed 3.482. Results show a significant Achievement Motivation difference between winner and loser groups.	-
Sharma et al. (2014)	India, National level (n=20)	The study's main purpose was to assess the personality traits of the elite Indian women's cricket players. 2013	Eysenck Personality Questionnaire (EPQ).	Female only. Homogenous. Poor.	The mean standard score was 49.60, with a standard deviation of 9.89 and a coefficient of variation of 0.516. The mean value of the standard score was 48.85, with a standard deviation of 11.17. The coefficient of variation was 0.659. The study's findings suggest that elite Indian women's cricket players exhibit stability in neurotic and	-

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
					extraversion personality traits. The hypothesis that elite Indian female cricket players would exhibit stability in neurotic traits has been confirmed. Elite female cricketers from India exhibit stability in the trait of extraversion. The results indicate stability in Extraversion among the subjects.	
Shweta and Deepak (2015)	India, National level (n=90)	The study aimed to see the effect of mental imagery training and concentration training in eliminating state anxiety and building o Year of study not reported.	The criteria chosen for the study were the scores obtained by the subjects in the Sports Competitive Anxiety Test by Rainer Martens and the Sports Self Confidence Questionnaire (SSCQ).	Female only. Homogenous. Fair.	The results show that mental imagery and concentration training help improve self-confidence and are also effective in moderating subjects' anxiety levels.	Based on the study's findings, mental preparation in sports is highly recommended to be given equal importance as technical skills.
Singh (2017)	India, Club level (n=60)	To assess the level of self-confidence of female cricket players from different states of North India. Year of study not reported.	Standard Hardy and Nelsons (1992) questionnaire for self-confidence was used to measure the self-confidence level of the subjects.	Female only. Homogenous. Fair.	Female cricket players from Haryana state exhibited greater self-confidence than players from Punjab and Delhi. Self-confidence is crucial in sports competitions, varying among players and events. However, it is influenced by various psychological factors.	-
Singh and Kumar (2023)	India, State level (n=30)	The purpose of the research study was to survey the psychological skills of state-level cricket players in India. Year of study not reported.	Michel J Mahoney's Psychological Skills Inventory (PSIS) was used for psychological surveying. Confidence, Motivation, Concentration, Mental Preparation, Team Emphasis and anxiety were the variables of the investigation.	Male and female. Heterogenous. Fair.	The study found no significant difference in anxiety levels between male and female cricketers. A significant difference was observed in the concentration levels between male and female cricket players. A significant difference was observed in the confidence levels of male and female cricket players. A significant difference was observed in the Mental Preparation level between male and female cricketers. Male and female cricket players had no significant difference in motivation levels. A significant difference was observed in the level of Team Emphasis between male and female cricket players. Female cricketers at the state level demonstrated higher concentration levels than their male counterparts.	Self-confidence is crucial in sports competitions, varying among players and events. Various psychological factors influence it.
Singh and Kaur (2016)	India, Club level (n=50)	This study aimed to compare the Sport Competition Anxiety between college-level male and female cricket players. Year of study not reported.	Sport Competition Anxiety Test (SCAT) developed by Martens et al. (1990).	Male and female. Homogenous. Fair.	The study found no significant differences between male and female cricket players from different colleges. Female inter-college cricket players experience higher levels of anxiety compared to their male counterparts.	-
Slathia et al. (2015)	India, Division level (n=40)	The present study aimed to determine the motivation between the male and female cricket players of	The Achievement Motivation Measure Test' constructed by Dr. M. L. Kamlesh.	Male and female. Homogenous. Fair.	This study investigated the disparity in motivation levels between male and female cricket players. The study found that male cricket players exhibit higher motivation levels than their female counterparts. The table compares the motivation levels between	-

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
		Jammu Division, J&K, India. Year of study not reported.			male and female cricket players. The mean values are 26.27 and 20.8, with standard deviations of 4.725 and 9.419, respectively.	
Van Rens et al. (2021)	Australia, State level (n=8)	This study aims to implement a 4-week pressure inurement training program in a state team of female cricket players and evaluate this program by observing changes in the players' stress responses and exploring their experiences with this program. Year of study not reported.	Challenge and Threat in Sport Scale (CAT-Sport), Trait Robustness of Self-Confidence (TROSCI), The Emotion Regulation Questionnaire (ERQ) as outcome measures. Intervention: 4-week Pressure inurement training (PIT) training block.	Female only. Homogenous. Fair	The findings from our research approach suggest that Pressure Inurement Training (PIT) shows promise as an effective intervention strategy. The effect sizes of PIT on challenge appraisal, self-confidence, threat appraisal, and reappraisal were found to be medium, positive, small, negative, and small, positive, respectively. No significant impact on suppression was observed. Additionally, findings from focus groups indicated that PIT enhanced the realism of players' training sessions, improved the effectiveness of the training, raised awareness of managing emotions and cognitive evaluation in high-pressure situations, and facilitated the development of psychological skills crucial for performing under pressure. The players highlighted the need to consistently monitor the level of difficulty and significance of stressors throughout the PIT program. They also reported experiencing negative emotions during the program.	To optimise PIT programs, players, coaches, and sports psychologists must collaborate throughout the program to optimize stressor difficulty and significance. Coaches and sports psychologists should adapt stress levels based on player feedback and circumstances. While most players had positive experiences with the PIT program, it was reported to cause negative effects and negatively impact subjective well-being. Players reported feeling frustrated and disappointed when they needed to meet their outcome goals. Thus, a registered sports psychologist should always supervise stress exposure training to ensure players mental health. All relevant coaching staff are aware of the PIT program to avoid additional stress.
Warmenhoven et al. (2020)	Australia, All levels (n=101)	To explore the different types of support and different support providers for female cricket players and to understand whether these support types or providers differ relative to level of skill expertise. Year of study not reported.	The comprehensive questionnaire examined various aspects, including demographics, socio-familial backgrounds, sport and competition history, chance factors, coaching, and athlete support.	Female only. Heterogenous. Good.	It was found that mothers and fathers were the leading providers of financial and emotional support, accounting for over 70% of support from both parents. Mentors also played a significant role by offering valuable sport-specific information and technical coaching support. Additionally, siblings and peers were vital as they acted as fellow participants during practice and play. The study found a significant difference in access to coaching between community and elite cricket players across all support providers ($p < 0.05$). The father's role as a primary provider of support for elite players was significant across five different dimensions of support ($p < 0.05$).	Elite female cricket players can access coaching and support providers with specific roles during athlete development. State and national sporting organizations should emphasize the father's role in athlete development and support. Future research and exploration are needed to capture female athletes' voices, experiences, and perspectives. This is required to create accurate educational and support strategies. The father dominated elite female cricketers' support in multiple ways.
Webster et al. (2017)	UK (England), Elite and county level (n=7)	The present research sought to better understand the multidimensional nature of team functioning and insight into the most important factors for team	Semi-structured interviews were conducted with 21 players, coaches, and psychologists involved in elite cricket, with resultant	Male and female. Heterogeneity. Fair.	Gender differences impact communication in teams. Female athletes must address conflict consequences promptly. Various factors indicate team effectiveness. A coach noted the team lacked physicality and in teamwork on and off the field. influential leadership is crucial, and a lack thereof negatively affects teams. The team's poor performance stemmed from a coach's lack of direction, a	The proposed model, derived from interviews with professional cricket players, coaches, and practitioners, offers a concise, sport-specific, and practical understanding of team effectiveness. Moreover, specific sex

Study	Study setting, level of play, female cricket sample (n)	Study aims, year of study.	Study outcome measures	Female only/male and female study, homogenous/ heterogenous of sample, data quality	Key findings	Practical implication
		effectiveness in professional cricket. Year of study not reported.	data analysed inductively initially, before being reanalysed deductively.		subpar captain's departure mid-season, and a general lack of leadership. Effective leaders inspire and ignite passion. Players highlighted the importance of understanding teammates' playing styles and personalities. Collaborative training enhances coordination. Both male and female players stressed the significance of trust between coaches and players for team motivation and commitment.	differences indicate more subtle aspects of team dynamics that could influence the communication style within male and female teams. It is recommended that individuals participating in female team sports consider the potential effects of conflict on relationships and promptly address such issues.
Yadav (2020)	India, Club level (n=44)	Purpose of the study was to compare the mental toughness ability among the semi-finalist teams. 2017-2018	Psychological Performance Inventory (PPI, Loehr 1986) questionnaire mental toughness was measured.	Female only. Heterogeneity. Fair.	The calculated F value of 4.71 was significantly higher than the table value of 2.46. The mental toughness of the semi-finalist teams varied significantly.	The psychology of cricket focuses on developing mental toughness using mental skills in practice and matches. It also offers expert guidance on understanding the key elements of successful teams and leaders.

Pressure Inurement Training (PIT), Standardized Concussion Assessment Tool (SCAT), standard deviation (sd), United Kingdom (UK)

CHAPTER 4. PHYSICAL PROFILES OF ALL-ROUNDERS, BATTERS, AND BOWLERS IN SUB-ELITE WOMEN'S CRICKET

The aims and objectives of this chapter are presented in **Ch. 1, pg. 4.**

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PAPER 2

Physical Profiles of All-rounders, Batters, and Bowlers in Sub-Elite Women's Cricket

Jolandi Jacobs, Benita Olivier, Corlia Brandt, Gandhi Jafta

Abstract

Introduction: The unique physical profile of each player's role in sub-elite women's cricket is vital for optimising performance as these players progress to the elite levels.

Objectives: This quantitative, cross-sectional study investigated the physical profiles of sub-elite women's cricket players as a group and compared these profiles across different player roles.

Inclusion criteria: Sub-elite female cricket players in the South African domestic women's cricket league were included in this study.

Methods: A battery of physical assessments was conducted at the start of the 2022/23 season. The physical assessments included body composition, individual muscle strength testing using dynamometry, 2km time trial (TT), countermovement jump (CMJ), single leg jump (SLJ), isometric mid-thigh pull, push-up and hop test on force plates.

Results: A total of 44 female players (20.86 ± 1.6 years) were included in the study. Differences were found in muscle mass (p=0.004) and peak power (p=0.040) for all-rounders and bowlers. Player roles presented with different dominant (p=0.006) and non-dominant (p=0.066) knee flexion strength. The bowlers' body composition and physical profile are compromised compared with batters and all-rounders. There were several physical strength and power differences between pace and spin bowlers in CMJ and SLJ tests for jump height (p=0.009) and peak power (p=0.006). Batters performed the best in the 2km TT.

Conclusion: Body composition and musculoskeletal profiles for each player role can be used as baseline markers in sub-elite women's cricket. Stakeholders can use this information to guide physical preparation for players advancing to elite levels.

Physical Profiles of All-rounders, Batters, and Bowlers in Sub-Elite Women's Cricket

Jolandi Jacobs, Benita Olivier, Corlia Brandt, Gandhi Jafta

4.1 Introduction

Women's cricket is drastically rising in participation and professionalism across the globe. The interest in women's cricket has also lured the sports science and medicine community in recent years (Letter et al., 2022a; Jacobs et al., 2022). Sports science and medicine researchers in cricket investigate musculoskeletal health with physical preparation, performance enhancement and injury prevention outcomes. The musculoskeletal system plays a crucial role in cricket, particularly in batting, bowling, and fielding. It enables athletes to make rapid changes in direction, accelerate, and maintain power and stability during gameplay. There is evidence to suggest that several physical factors, including body composition and muscle strength, have a significant impact on cricket performance (Dutton et al., 2019; Wormgoor et al., 2010). Therefore, prioritising the physical preparation of cricket players is crucial to achieve optimal performance.

It is essential to understand the physical profile of players to develop physical preparation guidelines in cricket. Physical preparation guidelines are widely researched in men's cricket (Weldon et al., 2021), including physical profiling for individual player roles such as bowlers and batters (Johnstone and Ford, 2010). The same is not evident for women's cricket because current research supporting physical

preparation for female cricket players focuses on female players as a group (Murphy et al., 2020) or explores the profiles of elite pace bowlers (Stuelcken et al., 2008a; Letter et al., 2022a; Letter et al., 2022b). Letter et al. (2022a) found that faster female pace bowlers possess superior physical characteristics, such as maximal upper body muscle strength, compared with slower pace bowlers. However, there was no difference in countermovement jump (CMJ) height among the faster and slower female pace bowlers (Letter et al., 2022a). Letter et al. (2022b) found changes in physical profiles between different age groups but no changes for seasonal assessments. Letter et al. (2022a) suggested that improving lower body strength, anaerobic capacities, and upper body pulling strength may enhance performance in female pace bowlers. Murphy et al. (2020) found a dominant arm internal rotation:external rotation strength deficit ratio in female cricket players and linked this with a 1.79 times increased risk of shoulder injury.

Differences exist between the physical profiles and demands among various player roles (Weldon et al., 2021; Johnstone and Ford, 2010). Identifying individual shortcomings and tailoring approaches to the sub-roles in cricket is crucial, considering each player's diverse demands and physical capacities (Weldon et al., 2021). The lack of existing research on the physical profiles of female cricket players, particularly those besides pace bowlers, is apparent. This dearth of information highlights the shortcomings of current sports science and medicine approaches in women's cricket. Extrapolating research findings from men's cricket and elite female pace bowlers to all female cricket players raises valid concerns. Comprehensive findings regarding the different player roles would be vital for developing and informing

strength and conditioning principles to enhance the physical preparation of the female cricket player (Weldon et al., 2021). Various physical parameters such as body composition, muscle strength, and aerobic fitness must be evaluated to investigate the differences between individual player roles.

Physical profiles of batters, wicketkeepers and all-rounders in women's cricket are unexplored and highlight a significant gap in the current literature. Moreover, there is a noticeable lack of research for sub-elite female cricket players. Therefore, the primary objective of this study was to investigate the physical profiles of sub-elite female cricket players. The secondary aim was to examine the differences in physical profiles between the different player roles. This study will provide practitioners in the field with baseline data when assessing the physical characteristics of batters, pace bowlers, spin bowlers, and all-rounders. These comparisons can facilitate the identification of strengths and weaknesses for each player role, thereby enabling the optimisation of goals within their existing physical preparation programs.

4.2 Methods

4.2.1 Experimental approach to the problem

A descriptive cross-sectional study was conducted on a cohort of sub-elite female cricket players. This study aimed to establish baseline values for the physical profiles of sub-elite female cricket players and compare the physical profiles across various player roles to assist the physical preparation for this cohort. The players were

classified into three primary categories: batters, bowlers, and all-rounders. A sub-analysis was performed on pace and spin bowlers. A standard performance test battery was selected to assess the physical profile of each player, and it consisted of body composition, physical strength, and aerobic fitness tests. The study was undertaken two weeks before the commencement of the 2022/2023 cricket season. Testing was done at the respective cricket unions' facilities and on two separate days. For the first testing day, players were assessed using a body composition test, isolated isometric strength assessments with a dynamometer and functional performance tests using force plates. On the second testing day, an aerobic fitness test was conducted. A supplementary document outlining testing procedures for this study can be found in **Ch. 4, Suppl. pg. 167-172.**

4.2.2 Subjects

The authors invited sub-elite female cricket players in the South African domestic women's league to participate in the study. The study included players who were injury-free on the day of testing, and testing was conducted two weeks before the commencement of the 2022/23 season. Three teams were selected to participate in the study, with 44 female cricket players who willingly participated. Ethical approval to conduct this study was obtained from the University of the Witwatersrand's Human Research Ethics Committee (Medical) and Cricket South Africa's (CSA) Independent Scientific Advisory Committee (**Appendix G**). All participants (including guardians of 18-year-olds and younger) gave their written informed consent for their data to be used in the study (**Appendix H**).

4.2.3 Procedures

The testing procedures were conducted on two separate days for each participant. On both days of testing, players were instructed to wear comfortable athletic attire and to warm up and stretch in their own accustomed way before testing. All testing procedures are summarised in the supplementary document (**Ch. 4, Suppl. Table 4-1, pg. 167-172**). After warming up, the players were instructed to rest for 10 minutes before testing started. On the first day, body composition and individual and functional strength tests were performed. There were 30 seconds of recovery time allowed between each trial of each test and five minutes of recovery time before advancing to a new testing procedure. On the second testing day, the individuals were asked to run a 2km time trial (TT) for aerobic fitness. One primary tester was responsible for instructing and capturing the tests, with support from trained assistants. The primary tester underwent extensive training in dynamometry and force plate testing with VALD software (VALD Performance, Brisbane, Australia). The primary tester did all the force plates and dynamometry instruction and capturing. The assistants were trained to capture the body compositions and assisted with capturing the 2km TT data.

4.2.4 Player characteristics

Players were classified as batters, bowlers or all-rounders by their coaches and according to the Cricket Consensus Statement (Orchard et al., 2016). A batter is a player who predominantly bats and is not required to bowl or keep wickets for most of the innings. Bowlers are classified as pace or spin bowlers. A wicketkeeper stands

close to the stumps when keeping for spin bowlers and positions further from the stumps for pace bowlers (Orchard et al., 2016). An all-rounder is a player who regularly bowls at least 10% of a team's overs and bats in the top seven batting positions for most of the innings.

4.2.5 Body composition

The body composition measurements were obtained utilising an Omron (Model OM-BF511) body composition scale (Omron BF306, Omron Healthcare, Inc., Vernon Hills, IL). There is good agreement between Omron and skinfolds measurements (bias = 0.2 ± 3.0%, p = 0.76) (Ihmels et al., 2006) and between Omron and Dual-energy X-ray absorptiometry (DEXA) (Lintsi et al., 2004). Body mass, body mass index (BMI), body fat percentage (BF%), muscle mass percentage (MM%) and resting metabolic rate (RMR) were all recorded for analysis.

4.2.6 Isolated muscle strength tests

Isometric muscle strength of the upper and lower extremities was assessed using a handheld dynamometer (DynaMo, VALD Performance). Participants were instructed to perform maximum voluntary contractions for three seconds for identified groups, including external shoulder rotators, internal shoulder rotators, quadriceps, hamstrings, and gluteus maximus muscles. Concurrent validity for isometric muscle strength testing with a dynamometer compared to Cybex showed fair to excellent

concurrent validity for the shoulder external rotators, knee flexors, knee extensors and hip extensors (Hébert et al., 2011). All muscle strength testing was conducted in the mid-range of the specific joint. The shoulder tests were performed with the player at 30° shoulder abduction, 30° scaption, 30° diagonal and 90° elbow flexion (Riemann et al., 2010) and using the DynaMo testing belts (indirect isometric resistance) for standardised testing procedures. The lower leg muscle strength tests were performed using the direct application of the dynamometry with the player in a prone position (Kelln et al., 2008). To standardise the measurements, the same testing individual who conducted the dynamometry tests was used to test all the players in all of the teams. The trial was immediately terminated if the tester detected compensatory movements, such as moving the humerus into shoulder abduction when external rotation was required or excessive lumbar extension during hip extension testing. The player was then requested to perform the test again without compensatory movements to standardise testing. A rest period of 30-seconds was allowed between each trial, including any incorrect trials (Letter et al., 2022a; Letter et al., 2022b). Each muscle group was tested three times, with the average value of the three tests recorded for data analysis.

4.2.7 Functional muscle strength tests

All functional muscle strength tests were done according to VALD ForceDecks protocols (**Ch. 4, Suppl. Table 4-1, pg. 167-168**). All tests conducted on the force plates were captured, cleaned, and analysed using VALD ForceDecks software (ForceDecks, VALD Performance). Jump testing using the force plates involved

participants starting at a normal mean force (N). The CMJ test, single leg jump (SLJ) test and hop test (HT) were used to determine lower body muscle strength and power. The isometric mid-thigh pull (IMTP) and a velocity push-up were used to assess upper-body muscle strength and power. Variables such as jump height, peak force, peak power, velocity at take-off and power are all reliable coefficients of variation (CV < 10%) (Souza et al., 2020). Inter-rater coefficients of variation are less than 0.6% for the SLJ, indicating good reliability for these tests (Matheson et al., 2013). Studies have indicated good inter-rater and intra-rater reliability for the IMTP test (Liu et al., 2020). The instructions for the jump test were to “jump as high as you can” and for the strength test to “push as hard as you can into the force plates.”

For all the jump tests, no arm swing was allowed. Each player had one testing trial for each test, with the tester correcting the player as needed. The testing trial was not recorded. After that, each participant’s body mass was recorded to normalise the data per body mass. Players were asked to perform three maximum trials for each test (CMJ, SLJ, HT, and IMTP). For the CMJ, SLJ and IMTP participants were asked to do a single repetition and were allowed 30 seconds of recovery time before another repetition was done (Letter et al., 2022a; Letter et al., 2022b). Players were allowed five minutes of rest before advancing to a new testing procedure. The average value of the three tests was recorded. For the HT, players had one trial of continuous jumps (Thomas et al., 2017). Players were requested to ‘jump as high as possible for 10 consecutive jumps’. The average peak force of five tests from a single testing trial was used for data analysis.

4.2.8 Aerobic fitness test

On a separate day from the body composition and strength testing, the players' aerobic capacity was determined by completing a 2km TT. Time trials have good re-test reliability (Laursen et al., 2007). The players were instructed to run a 2km time trial wearing their trainers around the boundary line of a cricket field. The 2km TT distance was measured beforehand for standardisation of the test. Only one trial of the 2km TT was captured for analysis.

4.2.9 Statistical analysis

All the data from the force decks, muscle strength tests, aerobic test, and body compositions were exported to Microsoft Excel (Microsoft 365, Microsoft Corporation, Washington, USA). For accurate analysis of left- and right-handers, we used the terms "dominant" and "non-dominant" when referring to either the left or right sides. Data were displayed as overall means and standard deviations for all variables. Further analyses investigated discrepancies between sub-groups, namely batters, bowlers (pace and spin) and all-rounders. Should the test have dominant and non-dominant variables, additional analyses were done to investigate whether the measurements differed for all participants. Analyses were done using either the t-test, Kolmogorov-Smirnov (KS), or Kruskal Wallis (KW) test. In all statistical tests conducted, the Shapiro-Wilk test was used for normality. We then compared the results of the batters, bowlers, and all-rounders using Analysis of Variance (ANOVA) or the KS test, depending on adherence to ANOVA assumptions (normality, equal variance and

independence). This was followed by testing for differences between pace and spin bowlers using the t-test or KS test, depending on the data distribution. The effect sizes were calculated using Cohen's d, omega squared, and eta squared. All statistical analyses were performed using R (version 4.2.2) and R Studio (version 2023.3.0.386) software (R Core Team, Vienna, Austria).

4.3 Results

4.3.1 Player characteristics

A total of 44 female participants with a mean age of 20.86 ± 1.60 years participated in the study. Players (n=44) were divided into subgroups for further analysis: batters (n=15), bowlers (n=15) and all-rounders (n=14). The bowlers were sub-divided into pace (n=19) and spin bowlers (n=9). There was one left-handed bowler and two left-handed batters.

4.3.2 Body composition

The body composition for each player role is indicated in **Table 4-1**. The total means for body composition can be seen in (**Ch. 4, Suppl. Table 4-2**). All-rounders had the highest overall body mass, BMI and MM% compared to other player roles. Bowlers had the lowest body mass and MM% compared to the other body roles. There was lower MM% (p=0.019, ES=0.18) and RMR (p=0.004, ES=0.23) for bowlers compared

to all-rounders (**Chapter 4, Suppl. Table 4-3 and 4-4**). Body composition analysis between pace and spin bowlers showed no major differences.

4.3.3 Isolated muscle strength tests

Isolated muscle strength of the upper and lower limbs of all player roles can be seen in **Table 4-1**. All-rounders had increased strength of dominant and non-dominant internal rotators (IR) and shoulder external rotators (ER) compared to batters and bowlers. Batters had increased rotational shoulder dominant and non-dominant strength compared to bowlers. Bowlers had the lowest overall muscle strength for both upper and lower muscle strength compared to batters and all-rounders. There were differences in shoulder IR for spin bowlers ($p=0.013$) and knee flexion for both pace ($p=0.001$) and spin bowlers ($p=0.014$) (**Ch. 4, Suppl. Table 4-5**). All-rounders had increased knee flexion, knee extension, hip extension, and muscle strength compared to batters and bowlers. Batters had the highest knee extension strength compared to all-rounders and batters. There were differences when implementing the KS test in dominant knee flexion for all the player roles (**Ch. 4, Suppl. Table 4-6**).

4.3.4 Functional muscle strength tests

Functional muscle strength tests for all player roles can be seen in **Table 4-1**. The total means for functional muscle strength tests can be seen in (**Ch. 4, Suppl. Table 4-2**). Analysis of the CMJ test indicated a difference ($p=0.04$, $ES=0.11$) in peak power for all-rounders compared to other player roles. For comparisons of CMJ between pace

and spin bowlers, there were differences in jump height (p=0.009, ES=1.24) and peak power normalised with body mass (p=0.006, ES=0.88). Analysis of the SLJ test indicated no significant differences between the dominant and non-dominant sides for all player roles. Further analysis of the SLJ demonstrated a difference in peak power (p=0.038, ES=0.34) of the non-dominant leg for batters compared to other player roles. There was a difference during the SLJ for non-dominant leg jump height (p=0.042, ES=0.86) for pace compared to spin bowlers. For the HT, the all-rounder had the highest peak power and batter the highest jump height compared to other player roles (**Table 4-1**).

Pace bowlers had higher jump height, mean landing rate of force development and peak power than spin bowlers. There were no differences among any player roles for the HT. Analysis of the IMTP indicated increased force generation for the entire test duration to be higher for the all-rounder than other player roles. There were no other differences among the player roles for the IMTP test (**Ch. 4, Suppl. Table 4-7**). Analysis of the push-up test indicated differences between dominant (p=0.001) and non-dominant sides for concentric mean force for all the players (**Ch. 4, Suppl. Table 4-2**). Bowlers had the highest concentric mean power compared with other player roles. Pace bowlers had higher concentric mean force on the dominant side than spin bowlers, but there was no difference between pace and spin bowlers.

Table 4-1: Group means, SD and p-value for body composition and musculoskeletal testing for sub-elite female cricket players per player role

Variables	All-rounder	Batter	Bowler	P-value	Effect sizes	Pace Bowler	Spin Bowler	P-value	Effect sizes
Body composition									
Body mass [kg]	70.14 ± 11.91	65.9 ± 9.0	62.09 ± 9.03	0.113[a]	0.10[z]	65.03 ± 10.37	66.75 ± 12.67	0.716	0.15[x]
BMI [kg/m^2]	24.27 ± 3.75	23.17 ± 3.2	23.17 ± 3.18	0.596[a]	0.02[z]	23.04 ± 3.03	24.27 ± 3.6	0.370	0.37[x]
Body Fat [%]	31.05 ± 7.27	31.07 ± 7.83	34.23 ± 5.59	0.365[a]	0.05[z]	31.54 ± 5.83	34.24 ± 7.94	0.358	0.39[x]
Muscle mass [%]	30.51 ± 3.32	29.5 ± 3.7	26.98 ± 3.08	0.019[a]	0.18[z]	29.12 ± 3.37	28.05 ± 4.31	0.507	0.28[x]
RMR [kcal]	1477.87 ± 111.03	1403.79 ± 104.46	1336.2 ± 114.01	0.004[a]	0.23[z]	1403.63 ±117.54	1400 ± 162.45	0.951	0.03[x]
Isolated muscle strength tests									
Shoulder IR (D) [N]	84.07 ± 33.62	71.79 ± 37.73	69.87 ± 24.19	0.465[b]	0.01[y]	74.05 ± 30.03	76.56 ± 25.61	0.814[c]	0.09[x]
Shoulder IR (ND) [N]	87.64 ± 31.39	74.86 ± 41.98	70.8 ± 20.31	0.163[b]	0.04[y]	74.05 ± 26.41	86.78 ± 28.7	0.342[c]	0.46[x]
Shoulder ER (D) [N]	69.21 ± 22.04	68.86 ± 32.27	63.73 ± 14.77	0.702[b]	0.03[y]	62.26 ± 15.31	74.00 ± 23.52	0.255[c]	0.59[x]
Shoulder ER (ND) [N]	70.14 ± 21.66	66.14 ± 27.15	63.67 ± 13.08	0.541[b]	0.02[y]	63.42 ± 13.92	72.44 ± 24.06	0.319	0.45[x]
Knee Flexion (D) [N]	205.87 ± 26.83	160 ± 32.51	170.73 ± 48.6	0.006[b]	0.20[y]	186.05 ± 42.53	186.80 ± 42.68	0.965	0.02[x]
Knee Flexion (ND) [N]	172.4 ± 27.77	140.79 ± 34.48	157.4 ± 36.41	0.066[b]	0.08[y]	161.05 ± 29.16	165.20 ± 34.23	0.749	0.12[x]
Knee Extension (D) [N]	230.27 ± 40.67	227.21 ± 93.86	197.33 ± 44.07	0.118[b]	0.05[y]	209.05 ± 48.16	217.20 ± 38.05	0.623	0.18[x]
Knee Extension (ND) [N]	217.47 ± 34.3	236.86 ± 116.61	201.87 ± 28.51	0.438[b]	0.01[y]	202.16 ± 32.00	221.70 ± 30.23	0.121	0.63[x]
Hip Extension (D) [N]	240.53 ± 57.15	224.14 ± 77.81	219.33 ± 46.21	0.419[b]	0.01[y]	236.26 ± 55.59	214.70 ± 46.25	0.279	0.42[x]
Hip Extension (ND) [N]	248.4 ± 41.77	218 ± 53.82	228.07 ± 69.34	0.289[b]	0.01[y]	246.74 ± 54.16	224.10 ± 65.19	0.361	0.38[x]

Internal rotation (IR), external rotation (ER), dominant (D), non-dominant (ND), body mass index (BMI), resting metabolic rate (RMR), rate of force development (RFD), countermovement jump (CMJ), single leg jump (SLJ), hop test (HT), time trial (TT), newton (N). P-value classifications: [a]ANOVA [b]Kruskal Wallis test [c]Kolmogorov (all other statistical tests were done using t-test). Effect size classifications: [x]Cohen's d [y]Kruskal Wallis (Eta squared) [z]ANOVA (Omega squared)

Variables	All-rounder	Batter	Bowler	P-value	Effect sizes	Pace Bowler	Spin Bowler	P-value	Effect sizes
Functional strength tests									
CMJ									
Jump Height [cm]	22.89 ± 4.85	23.52 ± 3.82	23.53 ± 2.85	0.880[a]	0.77[z]	24.54 ± 2.93	20.20 ± 4.01	0.009	1.24[x]
Peak Power [W]	2873.73 ± 64.70	2705.43 ± 389.14	2391.53 ± 479.78	0.040[b]	0.11[y]	2657.32 ± 640.52	2478.20 ± 512.16	0.585[c]	0.31[x]
Peak Power/ BM [W/kg]	41.73 ± 8.22	40.96 ± 3.39	38.44 ± 3.22	0.171[b]	0.03[y]	41.53 ± 7.20	36.78 ± 2.53	0.006[c]	0.88[x]
Peak Landing Force [N]	2848.07 ± 642.85	2925.21 ± 516.13	2839.93 ± 786.94	0.930[a]	0.86[z]	2703.42± 631.63	2962.90 ± 711.93	0.346	0.39[x]
SLJ									
Concentric Mean Force (ND) [N]	933.27 ± 163.42	928.14 ± 150.55	833.00 ± 117.22	0.118[a]	0.08[z]	879.00 ± 154.20	873.50 ± 142.14	0.924	0.04[x]
Eccentric Mean Force ND) [N]	716.13 ± 168.67	677.00 ± 123.43	611.00 ± 93.48	0.102[a]	0.12[z]	641.0 ± 105.48	693.30 ± 202.07	0.853[c]	0.32[x]
Jump Height (Flight Time) (ND) [cm]	10.47 ± 2.77	11.414 ± 2.43	11.20 ± 1.65	0.518[a]	0.80[z]	11.49 ± 2.14	9.63 ± 2.19	0.042	0.86[x]
Peak Power (ND) [W]	1634.07 ± 369.89	1730.93 ± 375.39	1414.20 ± 224.11	0.038[a]	0.34[z]	1545.74 ± 311.13	1461.60 ± 356.61	0.537	0.25[x]
Peak Power / BM (ND) [W/kg]	23.39 ± 4.78	26.24 ± 4.85	22.90 ± 2.44	0.079[a]	0.19[z]	23.77 ± 2.61	22.120 ± 5.40	0.381	0.39[x]
Peak Landing Force (ND) [N]	2261.4 ± 518.35	2166.43 ± 291.92	1966.47 ± 251.03	0.102[a]	0.12[z]	2156.63 ± 513.14	2021.10 ± 216.55	0.555[c]	0.34[x]
Concentric Mean Force (D) [N]	923.33 ± 171.26	905.14 ± 143.36	828.27 ± 123.77	0.187[a]	0.09[z]	871.00 ± 159.99	864.20 ± 144.30	0.909	0.04[x]
Eccentric Mean Force (D) [N]	711.20 ± 155.57	658.14 ± 105.04	611.67 ± 92.43	0.092[a]	0.15[z]	641.16 ± 106.11	686.60 ± 181.98	0.836[c]	0.31[x]
Jump Height (Flight Time) (D) [cm]	10.04 ± 3.07	11.11 ± 3.32	11.92 ± 2.03	0.206[a]	0.13[z]	11.63 ± 2.44	9.49 ± 2.83	0.059	0.81[x]
Peak Power (D) [W]	1573.60 ± 424.11	1544.79 ± 256.19	1510.07 ± 269.18	0.868[a]	1.63[z]	1559.95 ± 354.35	1438.10 ± 280.54	0.849[c]	0.38[x]
Peak Power / BM (D) [W/kg]	21.22 ± 8.01	23.59 ± 4.02	24.47 ± 3.11	0.260[a]	0.25[z]	24.02 ± 3.72	20.15 ± 9.08	0.225	0.56[x]
Peak Landing Force (D) [N]	2225.73 ± 38.06	2157.14 ± 407.14	2040.93 ± 87.13	0.556[a]	0.88[z]	2165.95 ± 96.20	2032.50 ± 220.83	0.668[c]	0.30[x]

IR = Internal rotation; ER = external rotation; D = dominant; ND = non-dominant; BM = body mass; BMI = body mass index; RMR = resting metabolic rate; RFD = rate of force development; CMJ = countermovement jump; SLJ = single-leg jump; HT = hop test; TT = time trial; N = Newton. P-value classifications: [a]ANOVA [b]Kruskal Wallis test [c]Kolmogorov (all other statistical tests were done using t-test). Effect size classifications: [x]Cohen's d [y]Kruskal Wallis (Eta squared) [z]ANOVA (Omega squared)

Variables	All-rounder	Batter	Bowler	P-value	Effect sizes	Pace Bowler	Spin Bowler	P-value	Effect sizes
Hop test									
Mean Active Stiffness [N/m]	24359.65 ± 8882.18	32685.31 ± 34177.79	22248.36 ± 6264.3	0.971[b]	0.05[y]	23253.5 ± 6775.3	25042.3 ± 8232.4	0.582	0.24[x]
Mean Jump Height (Flight Time)[cm]	22.53 ± 10.72	23.58 ± 5.1	22.72 ± 5.58	0.273[b]	0.15[y]	23.52 ± 9.15	20.83 ± 7.37	0.239[c]	0.32[x]
Mean Landing RFD [N/s]	37658.07 ± 13844.38	41906.21 ± 26658.12	36965.67 ± 8229.79	0.996[b]	0.05[y]	38872.7 ± 10551.8	35813.5 ± 12233.7	0.512	0.27[x]
Mean Peak Power [W]	6581.24 ± 7478.77	4830.42 ± 1422.85	4414.15 ± 1358.96	0.662[b]	0.03[y]	5929.62 ± 6688.92	4831.1 ± 1776.76	0.910[c]	0.22[x]
IMTP									
Force at 50ms [N]	947.79 ± 151.81	860.07 ± 207.53	803.37 ± 277.37	0.219[a]	0.03[z]	862.03 ± 266.94	881.56 ± 167.4	0.729[c]	0.09[x]
Force at 100ms [N]	1001.21 ± 154.65	937.00 ± 286.88	914.00 ± 216.15	0.567[a]	0.02[z]	954.11 ± 209.05	946.67 ± 164.86	0.920	0.04[x]
Force at 150ms [N]	1058.00 ± 167.40	973.36 ± 262.56	975.27 ± 217.93	0.509[a]	0.01[z]	1000.74 ± 216.56	1027.56 ± 159.05	0.716	0.14[x]
Force at 200ms [N]	1115.79 ± 182.19	1024.00 ± 271.11	1038.60 ± 233.6	0.534[a]	0.02[z]	1052.16 ± 230.07	1099.56 ± 163.48	0.539	0.24[x]
Peak Vertical Force [N]	1517.57 ± 336.28	1349.71 ± 242.96	1395.40 ± 296.99	0.307[a]	0.01[z]	1393.68 ± 298.02	1531.56 ± 331.75	0.307	0.44[x]
Push-up test									
Concentric Mean Power / BM [W/kg]	3.13 ± 0.46	3.30 ± 0.49	2.68 ± 0.41	0.111[a]	0.06[z]	2.86 ± 0.66	2.94 ± 0.85	0.824	0.10[x]
Concentric Mean Velocity [m/s]	0.46 ± 227.43	0.49 ± 220.00	0.41 ± 208.88	0.135[a]	0.05[z]	0.43 ± 0.09	0.44 ± 0.12	0.809	0.11[x]
Eccentric Mean Power / BM [W/kg]	2.56 ± 0.60	3.00 ± 0.94	2.52 ± 0.73	0.245[a]	0.02[z]	2.50 ± 0.73	2.63 ± 0.55	0.635	0.19[x]
Concentric Mean Force (ND) [N]	227.43 ± 0.73	220.00 ± 0.98	208.88 ± 0.60	0.372[a]	0.01[z]	217.87 ± 35.74	212.58 ± 26.79	0.577[c]	0.17[x]
Concentric Mean Force (D) [N]	254.54 ± 41.83	226.68 ± 30.85	213.46 ± 26.36	0.010[a]	0.18[z]	235.13 ± 39.83	225.49 ± 43.25	0.409[c]	0.23[x]
Aerobic fitness test									
2km TT [min]	11:02 ± 1:37	10:32 ± 1:28	11:14 ± 1:28	0.467[a]	0.04[z]	10:57 ± 1:19	11:05 ± 1:31	0.539[c]	0.10[x]

IR = Internal rotation; ER = external rotation; D = dominant; ND = non-dominant; BM = body mass; BMI = body mass index; RMR = resting metabolic rate; RFD = rate of force development; CMJ = countermovement jump; SLJ = single-leg jump; HT = hop test; TT = time trial; N = Newton. P-value classifications: [a]ANOVA [b]Kruskal Wallis test [c]Kolmogorov (all other statistical tests were done using t-test). Effect size classifications: [x]Cohen's d [y]Kruskal Wallis (Eta squared) [z]ANOVA (Omega squared)

4.3.5 Aerobic fitness test

The group means of the 2km TT results for all players can be seen in **Chapter 4, Suppl. Table 4-8** and per player role in Table 4-1. Batters had the lowest 2km TT times, followed by all-rounders and bowlers. There were no differences between the player roles. Further statistical analysis indicated no difference between pace and spin bowlers (**Ch. 4, Suppl. Table 4-10**).

4.4 Discussion

Our study found differences between the physical profiles and demands among various player roles in women's cricket owing to the distinct physical and technical capabilities demanded by each role. The investigation into the anthropometrics demonstrated that female cricket players presented with a BMI of 23.55 ± 3.35 kg/m^2, which is within the healthy body mass category compared to other studies on body composition in female athletes (Carbuhn et al., 2010; Vila et al., 2012; Milanese et al., 2011). The body mass of sub-elite female cricket players in this study (66.05 ±10.59kg) was comparable to that of elite female cricket players (Stuelcken et al., 2007; Johnstone and Ford, 2010; Murphy et al., 2020). Our study found that all-rounders presented with the highest body mass, BMI and MM%, whereas bowlers presented the lowest body mass, RMR and MM%. These findings were similar to elite men's cricket, where bowlers presented with lower body mass than batters (Weldon et al., 2021). Bowlers in our study presented with the highest BF% and batters with the lowest BF%. The overall body fat percentage reported in our study (32.14 ± 6.95%)

was higher than in other female sports (Carbuhn et al., 2010). The body composition of players is expected to vary depending on their specific player roles in cricket (Weldon et al., 2021; Johnstone and Ford, 2010). Cricket coaches, sports science and medicine staff should consider implementing individualised training and nutritional strategies to optimise body composition in each player role, thereby supporting their performance and overall health.

The aerobic fitness test showed superior performance by batters, followed by all-rounders and bowlers. The aerobic fitness results in our study for the sub-elite female cricket players present with overall slower time compared to the elite female cricket players (Letter et al., 2022a). Letter et al. (2022b) found that faster female pace bowlers are superior in all anaerobic capacity measures. It could be indicative that female pace bowlers are outperformed by batters as they might have more aerobic capacity compared to the anaerobic capacity of pace bowlers (Letter et al., 2022a). Our study observed that female batters had lower BF% compared to the bowlers, which aligns with the findings of the aerobic fitness test. Further research is needed to examine the aerobic fitness of players at the sub-elite level and determine the rationale behind the higher aerobic fitness observed in the female batters in our study.

Our study employed shoulder strength tests, push-up tests, and the IMTP to assess upper body strength. All-rounders demonstrated superior shoulder strength, IMTP and push-up results compared to other player roles. All-rounders presented with the biggest deficit in dominant IR:ER shoulder strength compared to other player roles. Dominant shoulder IR:ER deficit is linked to a risk of shoulder injury in elite female

cricket players (Murphy et al., 2020). Applied practitioners should aim for an IR:ER ratio to reduce the risk of dominant-side shoulder injury by maintaining a 1:1 ratio, specifically in the all-rounder cohort. Interestingly, batters and all-rounders had increased IR:ER shoulder strength in the non-dominant compared to the dominant shoulder. Future research should investigate the effect of increased shoulder IR:ER shoulder strength on technical performance during batting.

Sports science and medicine practitioners should also address these IR:ER deficits and increase overall shoulder strength by implementing shoulder strength and conditioning programs. Another interesting finding in our study is that bowlers presented with the weakest IR:ER shoulder strength compared to other player roles. One potential explanation for the comparatively lower shoulder strength observed in bowlers, as compared to batters and all-rounders, may be attributed to the repetitive and high-intensity nature of the bowling action. It is possible that bowlers might be more susceptible to shoulder injuries, leading to a reduction in shoulder strength over time. This is just a speculative explanation, and the actual reasons would require further investigation. Previous studies have found a correlation between shoulder extensor strength and ball release speed among sub-elite male pace bowlers (Feros et al., 2019). Applied practitioners should focus on the current physical preparation of female pace bowlers to enhance their overall shoulder muscle strength for improved performance in pace bowling. Additional research is necessary to investigate the relationship between shoulder strength and bowling performance in female pace bowlers.

For lower body strength testing, our study found increased dominant knee flexion strength compared to the non-dominant side for all player roles. Stakeholders in women's cricket should consider implementing strength and conditioning programmes to enhance hamstring muscle strength as a collective effort to reduce the disparity between dominant and non-dominant sides. Further research is needed to investigate this deficit and the effect of hamstring strength on female cricket players' performance. Subsequent examinations of various player roles revealed that all-rounders exhibited higher peak power in the CMJ and HTs in comparison to other player roles. Additionally, all-rounders exhibited greater muscle strength in knee flexion and hip extension than batters and bowlers. The scarcity of research on the physical attributes of all-rounders poses challenges in comparing our study's results to existing literature. It could be suggested that all-rounders dedicate more time to technical and physical development due to the multifaceted nature of their role, compared to individuals who only focus on bowling or batting. The increase in training volume could result in increased muscle strength, power, MM% and overall body mass, as seen in the results.

In our study, batters outperformed the bowlers in the CMJ. This finding is also evident in elite men’s cricket (Weldon et al., 2021). Batters also presented with higher muscle strength and muscle mass compared to bowlers. A notable discovery was that batters exhibited the greatest non-dominant knee extension strength. Investigations for the batters only revealed that the non-dominant leg exhibited greater peak power, concentric force, and jump height than the dominant leg. Batters showed the most significant deficit in knee flexion:extension ratio compared with other player roles.

Batters are expected to exhibit greater knee flexion angles and more repetitive knee flexion-to-extension motions during batting (Stuelcken et al., 2005). In addition to the distinctions above, it is noteworthy that batters exhibited the shortest 2km TT time, followed by all-rounders and bowlers.

An evident finding of this study was that bowlers had the lowest overall upper and lower muscle strength compared to all-rounders and batters. Further investigations should explore why spin bowlers have higher IMTP peak force than pace bowlers. Interestingly, pace and spin bowlers performed equally in the push test, whereas pace bowlers performed better than spin bowlers in men's cricket (Weldon et al., 2021). The physical demands and biomechanics also differ between spin and pace bowlers, as spin bowlers rely on muscles responsible for producing rotational movements (Spratford et al., 2020; Sanders et al., 2019). This could result in an increased focus on enhancing leg strength as part of their physical preparation (Mathankar and S, 2021), leading to higher IMTP scores than pace bowlers, as seen in this study. Pace and spin bowlers strongly emphasise their bowling skills, which demand technique over physical strength. In contrast, all-rounders and batters rely on muscular strength for powerful shots, resulting in boundaries (Taliep et al., 2010). Their higher IMTP scores demonstrate that batters and all-rounders may prioritise physical preparation over bowlers to develop upper and lower body strength.

Pace bowlers in our study presented with increased jump height and peak power compared to spin bowlers. Further testing identified a big difference in the non-dominant and dominant leg jump heights during the SLJ for pace bowlers compared

to spin bowlers. This finding is also evident in other research comparing male pace and spin bowlers (Weldon et al., 2021). Pace bowlers also presented with higher jump height and peak power than spin bowlers. There were differences in non-dominant leg jump height in pace bowlers compared to spin bowlers, which could be attributed to the bowling biomechanics of pace bowlers. Pace bowlers had reduced knee extension strength, but increased hip extension strength compared to spin bowlers. In male pace bowling, bowlers typically aim for minimal knee flexion at front foot contact, as a braced knee is advantageous for ball release speed (Portus et al., 2004). However, researchers have found that female subjects have different bowling biomechanics with a rotational pelvis and trunk rotation technique similar to throwing to generate momentum (Felton et al., 2019). The pace bowlers in our study presented with increased hip strength and reduced knee extension strength. This physical profile fits into the available research suggesting that female pace bowlers use techniques and muscles other than knee bracing to increase ball release speed. However, this is just speculation, and further research is needed to examine the muscles and biomechanics used by female pace bowlers.

This study offers important insights into the physical profiles of sub-elite women's cricket players, but some limitations must be acknowledged. The study sample was limited to a specific geographical area and a small cohort, potentially impacting the generalisability of the findings to other sub-elite female cricket populations. The study's cross-sectional design hinders the establishment of cause-effect relationships between musculoskeletal profiles and performance outcomes. The IMTP results were not normalised to body mass and may influence the study results. We suggest that

future researchers investigate shoulder strength testing in end ranges to explore the effects of eccentric muscle strength at longer muscle lengths. Also, future research should explore alternative assessments, such as an open kinetic chain test without end-range deceleration, like a medicine ball throw, to expand the scope of research for female cricket players.

This study portrays sub-elite female cricket players' body composition and physical profile for all player roles. The study aimed to bridge the knowledge gap in women's cricket by providing valuable insights into their physical characteristics and potential areas for strength and conditioning. Our findings indicate a dominant and non-dominant knee flexion strength deficit across all player roles. Moreover, evidence suggests that sub-elite all-rounders exhibit greater muscle strength, power, body mass, and muscle mass than bowlers. Bowlers displayed lower-muscle strength and body and muscle mass yet demonstrated higher jump heights than other player roles. Batters showed superior aerobic fitness capacity relative to other player roles. Considering the unique musculoskeletal profiles of each player role in sub-elite women's cricket is crucial for optimising performance as these players progress to the elite levels.

4.5 Practical implications

The findings of this study present physical differences between different player roles in women's cricket. The benchmark values from this study will enable applied sports science practitioners to guide physical preparation programs for individual player roles.

Applied practitioners should pay special attention to the physical profile of bowlers (pace and spin) because they present with reduced individual muscle group strength and functional muscle strength compared with other player roles. Also, body compositions for sub-elite pace and spin bowlers are compromised compared with batters and all-rounders. Bowlers should be given special consideration to increase muscle mass and strength, including the collaboration of the dietitian and strength and conditioning coach. For all player roles, hamstring muscle strength is significantly reduced in the non-dominant leg. Current physical preparation programs should aim to increase hamstring strength and close the deficit between the dominant and non-dominant sides. Batters as a group present with the lowest hamstring muscle strength compared with bowlers and all-rounders. All-rounders present with dominant shoulder IR:ER ratio deficit, predisposing them to shoulder injury. Practitioners should aim to increase the IR:ER ratio to 1:1 to reduce injury risk for all player roles, specifically for all-rounders.

4.6 Supplement to Paper 2

Supplementary Table 4-1. Musculoskeletal tests conducted for sub-elite women's cricket

Test	Equipment	Variables	The rationale of tests chosen	Test protocol
Body composition	Omron, Model OM-BF511	Body Mass Body Mass Index Body Fat Muscle Mass Resting Metabolic Rate	Objective scale to measure each variable for body composition.	Ihmels M, Welk GJ, McClain JJ, Schaben J. The Reliability and Convergent Validity of Field Tests of Body Composition in Young Adolescents. Journal of Physical Activity and Health. 2006; 3(s2):S67-S77. Lintsi M, Kaarma H, Kull I. Comparison of hand-to-hand bioimpedance and anthropometry equations versus dual-energy X-ray absorptiometry for the assessment of body fat percentage in 17-18-year-old conscripts. Clinical physiology and functional imaging. 2004; 24(2):85-90.
Individual strength	VALD Dynamo	Shoulder Internal Rotation Shoulder External Rotation Knee Flexion Knee Extension Hip Extension	All testing were done using hand-held dynamometry for objective measurement of strength testing. Trials were identified from a list of tests provided by VALD to be done using their software.	Shoulder IR: https://support.vald.com/hc/en-au/articles/14564824963481-DynaMo-Plus-Test-Shoulder-Strength-Protocol#7 Shoulder ER: https://support.vald.com/hc/en-au/articles/14564824963481-DynaMo-Plus-Test-Shoulder-Strength-Protocol#20 Knee Flexion: https://support.vald.com/hc/en-au/articles/19112858914329-DynaMo-Plus-Test-Knee-Strength-Protocol#5 Knee Extension: https://support.vald.com/hc/en-au/articles/19112858914329-DynaMo-Plus-Test-Knee-Strength-Protocol#14 Hip Extension:https://support.vald.com/hc/en-au/articles/19073392034713-DynaMo-Plus-Test-Hip-Strength-Protocol#6

Test	Equipment	Variables	The rationale of tests chosen	Test protocol
Functional strength	VALD ForceDecks	Countermovement Jump Single Leg Jump Hop Test Push-up Test Isometric Mid-Thigh Pull	All tests were done on forceplates for objective measurement of physical qualities. Trials were identified from a list of tests provided by VALD to be done using their software.	All VALD protocols were followed. Links for each of the protocols: Countermovement Jump: https://support.vald.com/hc/en-au/articles/4999886017817-ForceDecks-Test-Countermovement-Jump-Protocol Single Leg Jump: https://support.vald.com/hc/en-au/articles/4999875514393-ForceDecks-Test-Single-Leg-Jump-Protocol Hop Test: https://support.vald.com/hc/en-au/articles/4999906960153-ForceDecks-Test-Hop-Test-Protocol Push-Up: https://support.vald.com/hc/en-au/articles/4999827968665-ForceDecks-Test-Push-Up-Protocol Isometric Mid-Thigh Pull: https://support.vald.com/hc/en-au/articles/7667730369817-ForceDecks-Test-Isometric-Mid-Thigh-Pull-Protocol
Aerobic Fitness		2km Time Trial	Part of a battery of pre-tests as national requirements for each team.	2km timed run around the outfield of a cricket field (on grass) with trainer shoes (not cricket spikes) – as a requirement by the national cricket guidelines.

Supplementary Table 4-2. Total means for body composition and musculoskeletal testing for sub-elite female cricket players

Variables	Mean and Standard Deviation (±)	
Body composition		
Body Mass [kg]	66.05 ± 10.59	
BMI [kg/m^2]	23.55 ± 3.35	
Body fat %	32.14 ± 6.95	
Muscle mass %	28.98 ± 3.62	
RMR [kcal]	1406.00 ± 122.67	
Functional strength tests		
CMJ		
Jump Height [cm]	23.31 ± 3.85	
Peak Power [W]	2655.8 ± 553.45	
Peak Power / BM [W/kg]	40.36 ± 5.56	
Peak Landing Force [N]	2869.84 ± 646.67	
SLJ	*Non-dominant*	*Dominant*
Concentric Mean Force [N]	897.45 ± 149.08	885.14± 150.06
Eccentric Mean Force [N]	667.84 ± 136.68	660.39 ± 125.40
Jump Height (Flight Time) [cm]	11.02 ± 2.31	11.02 ± 2.89
Peak Power [W]	1589.93 ± 348.46	1542.77 ± 320.47
Peak Power / BM [W/kg]	24.13 ± 4.32	23.08 ± 5.56
Hop test		
Mean Active Stiffness [N/m]	26431.10 ± 20703.45	
Mean Jump Height (Flight Time) [cm]	22.93 ± 7.46	
Mean Landing RFD [N/s]	38773.70 ± 17437.69	
Mean Peak Power [W]	5285.38 ± 4510.18	
IMTP		
Force at 50ms [N]	868.85 ± 223.03	
Force at 100ms [N]	949.88 ± 223.26	
Force at 150ms [N]	1001.58 ± 217.75	
Force at 200ms [N]	1058.98 ± 229.88	
Peak Vertical Force [N]	1420.30 ± 296.16	

Variables	Mean and Standard Deviation (±)
Push-Up Test	
Concentric Mean Power / BM [W/kg]	3.02 ± 0.79
Concentric Mean Velocity [m/s]	0.45 ± 0.11
Eccentric Mean Power / BM [W/kg]	2.68 ± 0.79
Concentric Mean Force (Left) [N]	218.48 ± 34.07
Concentric Mean Force (Right) [N]	231.22 ± 37.07

Supplementary Table 4-3. ANOVA results for body composition in sub-elite female cricket players

Variable	Normality	Equal Variances	F-Statistic	P-Value
Body Mass [kg]	Yes	Yes	2.296	0.113
BMI [kg/m^2]	Yes	Yes	0.524	0.596
Body fat %	Yes	Yes	1.031	0.365
Muscle mass %	Yes	Yes	4.362	0.019
RMR [kcal]	Yes	Yes	6.220	0.004

Supplementary Table 4-4. Summary of Tukey HSD test for group analyses for body composition in sub-elite female cricket players

Variable	Roles	Mean difference	P-Value
Muscle mass %	All-rounder - Bowler	3.54	0.017
	Batter - Bowler	2.52	0.121
	All-rounder - Batter	1.01	0.702
RMR [kcal]	All-rounder - Bowler	141.67	0.003
	Batter – Bowler	67.59	0.236
	All-rounder - Batter	74.08	0.178

Supplementary Table 4-5. Left vs right muscle strength analyses for pace and spin bowlers in women's cricket

Variable	Bowler type	Test type	Test statistic	P-Value
Shoulder IR	Pace bowler	KS test	0.211	0.764
Shoulder IR	Spin bowler	t-test	3.207	0.013
Shoulder ER	Pace bowler	KS test	0.263	0.467
Shoulder ER	Spin bowler	t-test	-0.677	0.518
Knee flexion	Pace bowler	t-test	-3.889	0.001
Knee flexion	Spin bowler	t-test	-3.032	0.014
Knee extension	Pace bowler	t-test	-1.185	0.252
Knee extension	Spin bowler	t-test	0.834	0.426
Hip extension	Pace bowler	t-test	0.927	0.366
Hip extension	Spin bowler	t-test	0.609	0.558

Supplementary Table 4-6. Left vs right muscle strength analyses results for sub-elite female cricket players

Variable	Test	Test Statistic	P-Value
Shoulder Internal Rotation	t-test	0.116	0.911
Shoulder External Rotation	t-test	0.093	0.979
Knee FIexion	KS test	-5.826	6.551
Knee Extension	t-test	0.114	0.930
Hip Extension	t-test	0.521	0.605

Supplementary Table 4-7. ANOVA results for IMTP test for sub-elite female cricket players

Variable	F-Statistic	P-Value
Force at 50ms [N]	1.576	0.219
Force at 100ms [N]	0.575	0.567
Force at 150ms [N]	0.687	0.509
Force at 200ms [N]	0.637	0.534
Peak Vertical Force [N]	1.218	0.307

Supplementary Table 4-8. Analyses results for left vs right differences in push-up test of sub-elite female cricket players

Variable	Test	P-Value
Concentric Mean Force	Paired t-test	0.001

Supplementary Table 4-9. 2km time trial results of sub-elite female cricket players

Minimum	25th percentile	Median	Mean	75th percentile	Maximum
07:35 min	09:56 min	10:40 min	10:56 min	11:38 min	15:39 min

Supplementary Table 4-10. Analyses for 2km time trial of pace vs spin sub-elite female bowlers

Test	Test Statistic	P-Value
ANOVA	0.777	0.467
Kolmogorov-Smirnov	0.289	0.539

CHAPTER 5. INJURY PROFILES IN SUB-ELITE WOMEN'S CRICKET: EXPLORING INCIDENCE, PREVALENCE, NATURE, ONSET AND BODY REGION

The aims and objectives of this chapter are presented in **Ch. 1, pg. 4.**

This chapter is presented as a manuscript of an article under peer-review in Physical Therapy in Sport.

PAPER 3

Injury Profiles in Sub-Elite Women's Cricket: Exploring Incidence, Prevalence, Nature, Onset and Body Region

Jolandi Jacobs, Benita Olivier, Corlia Brandt

Abstract

Introduction: The rise in participation in sports, like women's cricket, is linked with increased injury risk. Providing high-level longitudinal data is the first step in implementing evidence-based injury prevention strategies.

Design: Prospective cohort study

Objective: This cohort study aims to describe the injury profiles in sub-elite women's cricket in South Africa during the 2022/23 season.

Methods: Injuries were prospectively recorded using injury surveillance questionnaires, injury surveillance database, and logbooks completed by each team's medical staff. Injury rates were investigated for match and training days, body region, player role, nature, and activity at the time of injury.

Results: Three teams with a total of 44 players (20.86 ± 1.6 years) were included in the study. Injury incidence was 85.23 per 1000 player match days, 15.91 for match time-loss and 69.32 for non-time-loss, with 2.95% of players unavailable for match selection on any day. Fast bowlers had the highest injury incidence. Fielding caused 46.67% of all injuries. Injury incidence was higher in training than in matches. The wrist/hand had the highest injury incidence and caused the most match time-loss.

Conclusion: This study provides valuable insights regarding the current injury rates in sub-elite female cricket players.

Injury Profiles in Sub-Elite Women's Cricket: Exploring Incidence, Prevalence, Nature, Onset and Body Region

Jolandi Jacobs, Benita Olivier, Corlia Brandt

5.1 Introduction

Sustaining an injury has been observed to diminish the likelihood of an individual's selection for professional sport (Hägglund et al., 2013). Injuries result in missed playing time, which reduces the effectiveness of the team's success and the individual's success in progressing in their career. Various injury prevention models, including the Translating Research into Injury Prevention Practice (TRIPP) framework (Finch, 2006), were developed to provide a structured approach for sports stakeholders to reduce the risk of injuries. The initial phase of the TRIPP model is to create a descriptive injury profile of the population, commonly referred to as injury epidemiology. Subsequently, injury epidemiology will guide the next stage of the injury surveillance framework (Finch, 2006). Epidemiological data can provide valuable insights to relevant stakeholders regarding injury rates, nature, body regions, player roles, and injury-related activities. Further, this information can inform the development of evidence-based injury prevention strategies to be implemented in practice.

Injury epidemiology is a well-researched concept in high-income cricket nations (Orchard et al., 2016). Several injury surveillance studies were published in women's cricket at the elite level cricket. According to a recent systematic review and meta-

analysis of women's cricket injury epidemiology (Jacobs et al., 2022), the injury incidence was 71.9 injuries per 1000 player hours, 13.3 time-loss injuries per 1000 player hours, and 58.5 non-time-loss injuries per 1000 player hours. According to the review, injury prevalence was higher in elite than non-elite levels, and shoulder and knee injuries were the most common. Fast bowlers had the highest prevalence, and fielders were the most likely to sustain wrist and hand injuries (Jacobs et al., 2022). Warren et al. (2019) investigated injury patterns in elite women's T20 (20 over) cricket in the United Kingdom (UK). The most common injuries were to the shoulder (1.8 injuries per 100 match days), lower back (1.7), and knee (1.7). The hand (1.7%), head/neck (0.8%), and thigh (0.6%) had the highest time-loss prevalence. The most time was lost due to catching-related injuries (2.5%), and throwing-related shoulder injuries were the most common (2.3 injuries per 100 match days) (Warren et al., 2019).

Orchard et al. (2023b) conducted a recent epidemiological study on injury rates in elite male and female Australian cricket players. The most common match time-loss injuries in female cricket players were hamstring strains (3.1 injuries per 100 players per season), concussions (2.3), quadriceps strains (2.4), and shin, foot, and ankle stress fractures (2.0). The authors then compared injury rates between male and female cricket players, establishing that males had higher match time-loss injury incidence and prevalence but similar medical attention injury rates. The observed differences in injury patterns between sexes indicate that injury prevention interventions should be adapted to the specific needs of each sex (Orchard et al., 2023b; Goggins et al., 2020a).

Despite the evidence of injury epidemiology in elite women's cricket (Orchard et al., 2023b; Jacobs et al., 2022; Warren et al., 2019), a knowledge deficit is evident at the sub-elite level. There remains a dearth of information regarding injury profiles in women's cricket at the sub-elite level. Therefore, injury prevention strategies implemented at the sub-elite women's cricket are based on either evidence retrieved at the elite level in women's cricket or the sub-elite level of men's cricket. The objective of this study was to establish the incidence and prevalence of injury in sub-elite women's cricket. Findings from this study may effectively guide injury prevention strategies and provide relevant information to stakeholders working with this population.

5.2 Methods

The Sports Injury and Illness Surveillance (STROBE-SIIS) (Bahr et al., 2020) and the International Consensus Statement (Orchard et al., 2016) guided the methodology of this longitudinal injury epidemiology study. The STROBE-SIIS checklist is available in **Appendix J**. Three teams were invited to participate in this study, and 44 female cricket players were voluntarily recruited. All subjects (including guardians of 18-year-olds and younger) gave their written consent for their data to be used in the study. Ethical approval and permission to conduct this study were obtained from Cricket South Africa's (CSA) Medical Research Committee, the respective cricket union managers, and the Human Research Ethics Committee (Medical). The three teams in this study participated in the 20 over and 50 over leagues that ran concurrently for the 2022/23 CSA Women's Cricket Domestic Season.

The season started in September 2022 and continued until November 2022 and, followed by a month break commencing January 2023. During the month break, the injury surveillance was paused and re-started in January till March 2023. Only injuries sustained during the official training and matches or other activities related to preparation for the domestic women's league were used as data for this injury surveillance study. During the season, the players were involved in other cricket leagues (such as club leagues and tournaments), and injuries sustained during these matches were not included in this injury surveillance study. A total of 20 matches were played by each of the three teams over a total of six months (excluding the one-month break), of which 10 matches were 50 overs and 10 were 20 overs matches.

Injury incidence data were obtained in three ways and compared to validate the data used in this study. First, the three medical teams were asked to log injuries over the season for data capturing for this study. Secondly, data was extracted from CSA's injury surveillance system. As part of CSA's national injury surveillance, medical health professionals used a platform, cricketclinic.com, to capture all injury and performance stats over the season. Finally, self-administered baseline and weekly questionnaires were administered using the Research Electronic Data Capture (REDCap) software (Harris et al., 2019) (**Appendix I**). These questionnaires were validated and used in previous injury surveillance studies in the cricket population (Olivier et al., 2015). Self-reported questionnaires were completed at the start of the season and weekly for the duration of the season. The questionnaire aimed to capture weekly self-reported non-time-loss injuries as these are frequently missed if they are not medical attention injuries. All self-reported injuries were discussed with the medical team and team coaches to correlate them with those recorded by the medical team in their logbook or

on cricketclinic.com. If the medical team knew of the self-reported injuries, the injury was captured as a self-reported non-time-loss injury. All time-loss injuries reported in this study were injuries recorded by the medical health professionals in their logbooks or on cricketclinic.com. The researchers screened the data on a weekly basis and had weekly meetings with the medical health professionals to compare self-reported injuries with those documented in the logbook, aiming to identify any time-loss and non-time loss injuries. Additionally, they correlated whether injuries were new occurrences or recurrent instances, i.e., the same injury recurring in the same season.

All definitions used in this study are per the 2016 Cricket Consensus Statement (Orchard et al., 2016). Player roles were classified as batters, bowlers, and wicketkeepers. Further sub-analysis was done for spin bowlers, fast bowlers, and wicketkeepers. All injury incidence or prevalence include "match time-loss" and "non-time-loss" injuries. Match time-loss is an injury that prevents a cricket player from being fully available for match selection, from batting, bowling, or keeping wickets as required by the rules or team captain. Non-time-loss is an injury that does not prevent sports participation (Orchard et al., 2016). A "medical-attention injury" is a medical condition that requires medical attention and may affect training or match play. A "player-reported" injury is self-reported without a medical diagnosis (Orchard et al., 2016). In this study, player-reported injuries were cross-checked with the medical team and recorded as non-time-loss if the medical team was unaware of the injury. This study investigated match time-loss injuries, training time-loss injuries and missed match and training days. Training time-loss was not included in any incidence or prevalence calculations but rather in a sub-analysis to compare missed match days with missed training days.

Exposure hours were calculated as a sum of the players in each squad multiplied by the number of match days and reported as player match days or exposure hours. Player match days were reported in recent cricket epidemiology studies (Warren et al., 2019; Goggins et al., 2020a; Orchard et al., 2023b) to exclude any confusion for mistaking exposure hours per player or team and for different exposure hours per format of cricket. All injury incidence calculations include both new and recurrent injuries. Injury incidence rates are reported as 1000 player match days for comparisons with other cricket injury epidemiology studies (Orchard et al., 2023b). Injury incidence rates and prevalence equations are displayed in **Table 5-1** (Orchard et al., 2016; Goggins et al., 2020b; Warren et al., 2019):

Table 5-1: Equations for incidence and prevalence

Player match days =	daily squad size x number of match days
Player training days =	daily squad size x number of training days
Injury incidence rate =	$\frac{\text{time-loss / non-time-loss injuries x 1000}}{\text{player match days}}$
Match time-loss prevalence =	$\frac{\text{players unavailable for matches x 1000}}{\text{player match days}}$
Match time-loss (per 1000 exposure hours) =	$\frac{\text{match time-loss injuries x 1000}}{\text{match exposure hours}}$
Training time-loss (per 1000 exposure hours) =	$\frac{\text{training time-loss injuries x 1000}}{\text{player match days}}$

The incidence and prevalence rates were analysed using the formulas above as descriptive statistics in Microsoft Excel (Microsoft 365, Microsoft Corporation, Washington, USA).

Statistical analyses

The incidence and prevalence rates were analysed using the formulas above as descriptive statistics in Microsoft Excel (Microsoft 365, Microsoft Corporation, Washington, USA).

5.3 Results

A total of 44 participants with a mean age of 20.86 ± 1.60 years participated in the study. A total of 75 injuries (14 time-loss and 61 non-time-loss) (46 new injuries, 29 recurrent injuries) were recorded over one cricket season (extra descriptive data for injury counts and incidence calculations is available in the supplementary document). Training sessions were 2 hours per session, and matches per team for ODI was 43.3 hours per match per team, and T20 14.7 hours per match per team. Players were exposed to 6336 training hours (3168 player training days) compared to 1740 hours in 20 matches (880 player match days). Most injuries occurred during matches (46.67%) and training (49.33%). Time-loss injuries occurred almost equally in training and matches. Illness complaints were initially recorded in this study but only occurred twice during the season and did not result in any time-loss; hence, illness is deliberately excluded from this study.

5.3.1 Injury incidence

The injury incidence of all injuries was 85.23 per 1000 player match days. Time-loss injuries were 15.91 per 1000 player match days and 69.32 for non-time-loss injuries. Match injury incidence in 20 overs was 21.59 per 1000 player match days compared to 50 overs injury incidence of 17.05 per 1000 player match days (**Table 5-2**).

Table 5-2: Incidence of injuries in sub-elite women's cricket by cricket format and player role (per 1000 player match days)

	Time-loss incidence rate (per 1000 player match days)	Non-time-loss incidence rate (per 1000 player match days)	Injury incidence rate (per 1000 player match days)
All	15.91	69.32	85.23
Per format of cricket:			
All matches	6.82	32.95	39.77
- T20 match	*4.55*	17.05	*21.59*
- ODI match	*2.27*	14.77	*17.05*
Training	n/a	30.68	*n/a*
Other	n/a	5.68	*n/a*
Per player role:			
All-rounders	6.82	23.86	30.68
Batters *(including wicketkeepers)*	3.41	22.73	26.14
Bowlers *(all)*	5.68	22.73	28.41
Per player role (sub-analysis):			
Fast bowlers	7.95	34.09	42.05
Spin bowlers	4.55	12.50	17.05
Wicketkeepers	0	6.82	6.82
Batters	3.41	15.91	19.32

Injuries resulted in a total 17.11 hours missed for matches and 123.97 hours missed in training. Overall, match time-loss prevalence was 2.95% of players unavailable for selection on any given match day and 29.55 matches missed per 1000 player match days. Training time-loss prevalence was 5.87% of players unavailable to participate in training on any given day. The injury incidence rate for missed training days was 24.62 per 1000 player training days. For time missed due to injury, player match days were converted to exposure hours to compare match and training time-loss. The match time-loss injury incidence rate was 8.05 per 1000 exposure hours, and the training time-loss injury incidence rate of 4.42 per 1000 exposure hours. Wrist/hand injuries caused the most time missed in matches, followed by lower leg and shoulder.

5.3.2 Injuries per body region and player role

Injury incidence (time-loss and non-time loss) per body region can be seen in **Table 5-3**. The highest injury incidence occurred in the wrist/hand, knee, and lower leg. The highest time-loss injuries occurred in the lower leg, ankle, and wrist/hand. Fast bowlers had the most match time-loss injuries, followed by slow bowlers. All-rounders had the highest injury incidence compared to bowlers and batters. Further sub-analysis indicated that fast bowlers are more frequently injured when compared to batters, slow bowlers, and wicketkeepers (**Table 5-2**).

Table 5-3: Incidence of body region injured per player role in sub-elite women's cricket (per 1000 player match days)

	Ankle	Elbow	Head/ neck	Hip/groin	Knee	Lower back	Lower leg	Shoulder	Thigh	Wrist/hand
All	9.09	3.41	4.55	6.82	13.64	3.41	12.50	9.09	6.82	17.05
Time-loss	3.41	1.14	0.00	0.00	1.14	1.14	3.41	1.14	1.14	2.27
Non-time-loss	5.68	2.27	4.55	6.82	12.50	2.27	9.09	7.95	5.68	14.77
Per player role:										
Batter	1.14	2.27	2.27	1.14	1.14	0.00	2.27	1.14	2.27	5.68
All bowlers	7.96	1.14	1.14	5.69	9.09	3.41	10.23	6.82	3.41	10.23
- *Fast bowler*	6.82	1.14	1.14	4.55	5.68	2.27	6.82	5.68	3.41	4.55
- *Spin bowler*	1.14	0.00	0.00	1.14	3.41	1.14	3.41	1.14	0.00	5.68
Wicketkeeper	0.00	0.00	0.00	0.00	3.41	0.00	0.00	1.14	1.14	1.14

5.3.3 Activity, onset and nature of the injury

The nature of injuries per activity of injury is reported in **Table 5-4**. Players sustained the most injuries during fielding (46.67%) compared to bowling (25.33%), strength and conditioning (8%), batting (6.67%) and keeping (5.33%). Injuries were more common on the dominant (54.67%) compared to the non-dominant side (32%). The incidence of new injuries (52.27 per 1000 player match days) was higher than that of recurrent injuries in the same season (7.95).

Table 5-4: Incidence of the nature of injuries per activity of injury in sub-elite women's cricket (per 1000 player match days)

Player role	Fielding	Bowling	Batting	Strength and Conditioning	Wicketkeeping
Muscle injury	13.64	14.77	4.55	5.68	3.41
Bone and ligament/ joint injury	20.45	6.82	0.00	0.00	1.14
Concussion	1.14	0.00	0.00	0.00	0.00
Superficial tissue/ skin	4.55	0.00	1.14	0.00	0.00
All	39.77	21.59	5.68	5.68	4.55

Most new injuries occurred in the wrist/hand and during fielding. The most recurrent injuries occurred in the lower leg, knee and ankle and sustained during fielding and bowling. The most match time-loss injuries occurred during fielding. The incidence of direct contact injuries (61.33%) was higher than non-contact injuries (38.67%). Most recurrent injuries were non-contact injuries (75.86%). Recurrent injuries were linked

to injuries sustained in previous seasons (47.83%) rather than the current season (15.22%). Direct contact with the ball had higher incidences (20%) than contact with the ground (12%). Sudden onset injuries (64%) had higher incidences than gradual onset injuries (36%). Medical attention injury incidence was 30.68 injuries per 1000 player match days, including a time-loss of 15.91 injuries per 1000 player match days. All time-loss injuries were medical attention injuries. The highest muscle-related injuries were in the lower leg and shoulder and sustained mainly by fast bowlers. The most joint-related injuries occurred in the wrist/hand and were more prevalent in slower bowlers. Additional calculations and data presentations are available in **Ch. 5, Suppl. pg. 195-200**.

5.4 Discussion

This study fills a vital research gap regarding injury epidemiology in sub-elite women's cricket. To the authors' knowledge, this is the first study to provide a detailed profile of the incidence rate and prevalence of injuries among the sub-elite female cricket population. The injury incidence rate in 20-over cricket was higher (21.59 per 1000 player match days) than in 50-over matches (17.05 per 1000 player match days). The intensity of cricket played during 20 overs is higher than in longer game formats. It could be the reason for increased injury incidence, despite the reduced exposure hours compared to 50 overs. In our study, the injury incidence rate for sub-elite women's cricket was 85.23 per 1000 player match days, 15.91 for time-loss and 69.32 for non-time-loss. The injury incidence rate was higher among UK international pathway women's cricket (182.5 per 100 players per year) and UK elite women's cricket (143 injuries per 1000 match days) (Goggins et al., 2020b; Warren et al., 2019).

Match time-loss was lower for the sub-elite level cricketers in this study compared to elite level women's cricket. Match time-loss in elite Australian women's cricket was 101 injuries per 1000 match days (Orchard et al., 2023b) and 2.1 time-loss injuries per 100 match days in elite UK women's cricket (Warren et al., 2019). However, the incidence of match time-loss injuries in this study was higher (15.91 per 1000 players per year) than in UK international pathway women's cricket (7.0 per 1000 player match days). Further, 2.95% prevalence of time-loss injury reported in this study was lower compared to other women's cricket studies; 6.5% in elite Australian women's cricket, 4.6% in UK elite cricket and 4.1% in UK international pathway cricket (Orchard et al., 2023b; Warren et al., 2019; Goggins et al., 2020b).

The lower prevalence and incidence of time-loss injuries among sub-elite women's cricket in our study, as opposed to the higher rates reported in the pathway and elite levels, may be attributed to several factors. Firstly, some studies, such as the UK international pathway cricket (Goggins et al., 2020b), report illness in addition to injury, which could be the reason for the higher rates compared to this study. Illness was intentionally excluded from this injury epidemiology study, as in several other cricket studies (Orchard et al., 2023b), as it was not associated with missed match or training time. Another factor could be related to the reduced professionalism at the sub-elite level compared to the elite levels. Only five players per franchise team in this study had formal contracts compared to international pathway cricket, where all players have part-time contracts (Goggins et al., 2020b) and elite level, where all players have full-time contracts (Orchard et al., 2023b). Without professional contracts and financial support, sub-elite players participate in cricket training and matches based on their work and personal schedules, reducing their commitment to invest in their own and

the team's skill development and performance. Less training time and reduced intensity and frequency will lower the risk of injury. The female participants in this study are younger than other women's cricket studies (Orchard et al., 2023b; Perera et al., 2019c; Warren et al., 2019), and have reduced experience and exposure to skills development as elite cricket players. Players at non-elite levels have limited skill development, match exposure, and physical capacity compared to elite levels of the sport (Kelly et al., 2019). Future research in cricket should investigate factors such as bowling speed, training load, match schedule, access to equipment and specialised coaching and the risk of injury at the sub-elite level.

An interesting finding of this study was the higher training time-loss prevalence compared to match time-loss prevalence. There was also more training in injury incidences compared to matches. International women's pathway cricket in the UK also reported that the highest medical complaint injuries occurred during training rather than matches (Goggins et al., 2020b). The technical demands of traditional net-training sessions exceed that of a typical match for each playing position, specifically bowlers (Vickery et al., 2018b). Training also exposes players to direct contact and non-contact risks. Contact injuries could be more frequent because players are exposed to different dangers during training. The increased contact risk, for example, can be multiple balls in play during training compared to matches as more than one stimulated play is happening during net sessions or more than one ball during fielding sessions.

The high incidence of training-related injury could be a reason for the frequency of catching compared to in a match. Players are exposed to different conditions during

training, such as other surfaces during fielding and inside and outdoor nets, different playing conditions and intensity, and increased frequency of batting, bowling and fielding that could contribute to non-contact injuries. Besides the higher training injury incidence, match-related injuries caused the most missed time due to an injury. The increased missed time for match-related injuries could be linked to the higher intensity of match play than training. Players would likely resume earlier to training to then matches. A staggered return to matches is expected, as the intensity of cricket is higher in matches than in training, and the risk of injury is higher. Players might go to extremes in matches to take catches, dive to reduce runs, bowl quicker or run faster compared to training.

The highest time-loss injuries occurred in the lower leg and ankle and were sustained mainly by fast bowlers. Also, most non-contact muscle-related injuries occurred in the ankle and lower leg. The high incidence of lower limb injuries reported in this study is similar to other women's cricket studies (Warren et al., 2019; Perera et al., 2019c; Orchard et al., 2023b). Joint and muscle-related injuries are concerning as these injuries can cause long-term health effects in retired cricket players (Cai et al., 2019; Jones et al., 2018a). The anatomical differences in female athletes can predispose female cricket players to an increased risk for lower limb injuries. Female athletes are predisposed to ankle ligament laxity and poor dynamic postural control, increasing the risk of injury (Ericksen and Gribble, 2012). Future research should investigate female health and the effect of these factors on lower limb injury rates specifically at the sub-elite levels.

Fasat bowlers had the highest injury incidence (time-loss and non-time-loss), muscle-related injuries and most missed time due to an injury compared to spin bowlers and batters in our study. The kinetic and kinematic risk factors for female fast bowlers could be linked to the high injury rates. Fast bowlers were also the player role with the most injuries in elite women's cricket in Australia (Perera et al., 2019c) and the UK (Warren et al., 2019). Evidence suggests that female fast bowlers are exposed to kinematic and kinetic injury risks compared to slower bowlers and other player roles (Stuelcken et al., 2010b; Stuelcken et al., 2010a; Stuelcken and Sinclair, 2009). Female fast bowlers with back pain have increased left lateral flexion relative to the pelvis during the delivery stride compared to bowlers with no lower back pain history (Stuelcken et al., 2010b). The distraction force in the shoulder could also contribute to a shoulder injury in female fast bowlers (Stuelcken et al., 2010a). Injury risks are linked with ground reaction forces on the back foot and front foot contact during the bowling action (Stuelcken and Sinclair, 2009). Fast bowlers also have increased training and match volumes compared to other player roles (Petersen et al., 2010; Vickery et al., 2018b). Injuries in all-rounders (players with a batting and bowling role in a team) were investigated to determine if this population had a higher incidence rate than only batters or bowlers. As expected, the incidence rate of all-rounders was higher when compared to bowlers and batters.

Almost 50% of injuries during the season were fielding-related injuries. Fielding was also the activity that caused the most injuries in elite and pathway cricket in the UK (Warren et al., 2019). Catching-related injuries caused the most time-loss injuries in elite T20 women's cricket (Warren et al., 2019; Goggins et al., 2020b). Fielding injuries are overrepresented in the female cricket population compared to males. Our study

reported that 61.33% of all fielding injuries were direct contact injuries. Contact with the ball resulted in 32.61% of all contact injuries and contact with the ground resulted in 19.57%. Other women's cricket epidemiological studies also report a high incidence of contact injuries (Warren et al., 2019; Basu et al., 2021; Perera et al., 2019c). Future research should investigate the intensity of fielding activities and compare this to math intensity. For example, fielders need to be exposed to catching and fielding balls that are hit at high speed towards them and need to stop boundary balls by diving. Furthermore, research should investigate the implementation strategies of ground fielding and diving techniques as several fielding injuries are related to ground impact in this study. This study reports that 8% of all injuries were sustained during strength and conditioning activities, more than batting-related injuries. Future research is needed to investigate of strength-based training is a risk for injury. Future studies must explore the nature of training modalities specifically at the sub-elite level to explore whether strength and conditioning pertain to a risk of injury in sub-elite women's cricket.

The high incidence of wrist/hand injuries among this sub-elite cohort is concerning compared to other body regions. The highest direct contact and joint-related injuries also occurred in the wrist/hand. Most of these injuries were sustained during fielding. Other women's cricket studies also reported a high incidence of wrist/hand injuries compared to other body regions (Perera et al., 2019c; Goggins et al., 2020b; Warren et al., 2019). There was also more acute onset than gradual injuries and more new injuries than recurrent injuries among this sub-elite women's cricket population. The high incidence of acute onset and new injuries can be linked to the high incidence of direct contact injuries. Most direct contact injuries occurred with the ball or the ground

during fielding. Female cricket players could have developed catching and ground fielding techniques that predispose them to injury. Cricket players face several risks during fielding: contact with the ball, falls, boundary rope, and contact with the ground. Research is needed to identify fielding related factors such as hand-eye coordination and visual reaction time to risk of contact injury at the sub-elite level. Research has indicated long-term osteoarthritis and other health outcomes in retired elite cricket players (Jones et al., 2018a). Osteoarthritis, total hip and knee replacements are more prevalent in former cricket players compared to the general population (Cai et al., 2019). Reducing the number of direct contact injuries in women's cricket is vital for better long-term health outcomes after a cricket career and an indication for future research.

A limitation of this study is the small population size and potential consequences on external validity. Another limitation is the lack of detailed information regarding the cohort's playing history, age of commencement in cricket, number of seasons played at the sub-elite level, and involvement in additional sports, which could potentially impact injury rates and limit the generalisability of the findings. A strength of this study is the rigorous methodology, including three data sources to verify the data collection and reporting. All self-reported injuries were confirmed with medical team members. A strength of this study is that all injuries sustained during matches and training and time missed for these were reported for an objective overview of all injuries sustained in sub-elite women's cricket. This study is the first to examine injury profiles in sub-elite women's cricket in South Africa. This study provided a comprehensive profile of injuries in this population by examining the injury's nature, onset, activity, player roles, body region, and time missed due to injury.

5.5 Conclusion

This study provides evidence-based injury rates in sub-elite women's cricket that can be used as the first step to guide injury prevention programs, specifically in South African women's and other sub-elite women's cricket populations. Injury incidence for sub-elite women's cricket (including time-loss) is lower than at elite levels. Fast bowlers had the highest injury incidence. Fielding was the activity that caused the most injuries. Wrist/hand had the highest incidence and caused the most missed time due to injury. Future research should focus on reducing the incidence of direct contact injuries, particularly during fielding. Research is needed to investigate catching techniques and ground movements during fielding to identify possible injury risk factors.

5.6 Practical implications

Injury prevention strategies must be implemented to reduce direct contact injuries, specifically during fielding (e.g. catching the ball without injury and taking the ground during fielding to minimise the injury risk). Injury prevention strategies must be implemented to reduce the high injury incidence among female fast bowlers. Physiotherapists and other medical staff should be appointed at the sub-elite level to manage the high incidence of direct contact injuries in matches in training.

5.7 Supplement to Paper 3

Summary of findings of injury profiles in sub-elite women's cricket:

- Injury incidence was 85.23 per 1000 player match days, 15.91 for match time-loss and 69.32 for non-time-loss.
- 2.95% of players were unavailable for selection on any given match day due to injury.
- 5.87% of players were unavailable to participate in training on any given day due to injury.
- The body region with the highest incidence was the wrist/hand.
- The player role with the highest injury incidence was fast bowlers.
- The activity that caused the most injuries during the season was fielding.
- Most of the injuries occurred in the dominant side of the injured players (54.67%) versus the non-dominant side (32%).
- Direct contact occurred more than non-contact injuries.
- New injuries occurred more frequently than recurrent injuries.
- Muscle injuries had higher incidences than bone and ligament/joint injuries.
- Acute onset injuries occurred more than gradual onset injuries.

Supplementary Table 5-1. Total injuries sustained during matches and training over a season in sub-elite women's cricket

Cricket format	Injuries (all)	Injuries (time-loss)	Injuries (non-time loss)
All matches	35	6	29
20 over match	*19*	*4*	*15*
50 over match	*16*	*2*	*14*
Training	*34*	*7*	*27*
Other	*6*	*1*	*5*
All	75	14	61

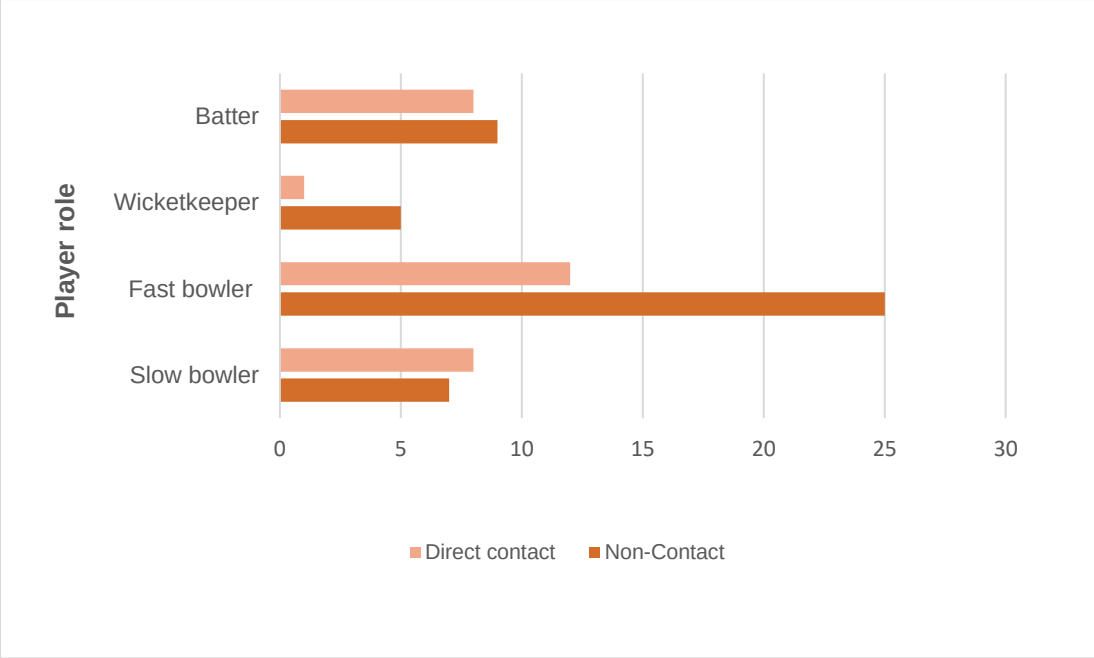
Supplementary Table 5-2. Description of injury incidences over one season in sub-elite women's cricket

	Total % of all incidences (75)	Injury incidence rate (per 1000 player match days)
Dominant vs non-dominant side injury		
Dominant side injury	54.67%	46.59
Non-dominant side injury	32%	27.27
Both sides or central injury	10.67%	9.09
N/a	2.67%	2.27
New vs recurrent injury		
New injury	61.33%	52.27
Recurrent injury	38.67%	32.95
New vs recurrent injury		
New injury	61.33%	52.27
Recurrent (current season)	9.33% *(15.22% of all recurrent injury)*	7.95
Recurrent (previous season)	29.33% *(47.83% of all recurrent injuries)*	25.00
Direct contact vs non-contact injury		
Direct contact	61.33%	52.27
Non-contact	38.67%	32.95
Direct contact		
Contact with the ball	20% *(32.61% of direct contact injuries)*	17.05
Contact with the ground	12% *(19.57% of direct contact injuries)*	10.23

	Total % of all incidences (75)	Injury incidence rate (per 1000 player match days)
Onset of injury		
All	100%	85.23
Sudden	36%	30.68
Acute	64%	54.55
Gradual injuries (all)		
1 week	20%	17.05
2 weeks	10.67%	9.09
3 weeks	4.00%	3.41
> 4 weeks	1.33%	1.14
Activity that caused injury		
Batting	6.67%	5.68
Bowling	25.33%	21.59
Fielding	46.67%	39.77
Strength and conditioning	8%	6.82
Wicketkeeping	5.33%	4.55
Medical attention injuries		
All	36%	30.68
Time-loss*	18.67%	15.91
Non-time-loss	17.33%	14.77

Supplementary Table 5-3. Incidence of contact and non-contact injuries per player role in sub-elite women's cricket (per 1000 player match days)

Player role	Direct contact injuries	Non-contact injuries	Total injuries
Batter	9.09	10.23	19.32
Wicketkeeper	1.14	5.68	6.82
Fast bowler	13.64	28.41	42.05
Spin bowler	9.09	7.95	17.05
Total	32.95	52.27	85.23



Supplementary Figure 5-1. Contact and non-contact injuries per player role in sub-elite women's cricket

Supplementary Table 5-4. Incidence of the nature of injuries per activity of injury in sub-elite women's cricket (per 1000 player match days)

Player role	Concussion	Superficial tissue/ skin	Bone and ligament/ joint injury	Muscle injury	All
Batter	1.14	2.28	6.82	9.09	19.32
Fast bowler	0	3.41	11.36	27.27	42.05
Spin bowler	0	0	11.36	5.68	17.05
Wicketkeeper	0	0	1.14	5.68	6.82
All	1.14	5.69	30.68	47.73	85.23

Supplementary Table 5-5. Matches missed per body region injured in sub-elite women's cricket

Body region	Matches missed
Wrist/hand	6
Lower leg	5
Ankle	4
Shoulder	3
Lower back	3
Head/face	2
Thigh	1
Elbow	1
Knee	1
Total	26

Supplementary Table 5-6. Total matches missed due to injury in sub-elite women's cricket

Duration of injury	Count	Matches missed
1 match	6	6
2 matches	5	10
3 matches	2	6
4 matches	1	4
1 match	6	6
Total	-	26

Supplementary Table 5-7. Total training time missed due to injury in sub-elite women's cricket

Duration of injury	Count	Weeks missed	Sessions missed
1 week	6	6	18
2 weeks	5	10	30
3 weeks	2	6	18
4 weeks	1	4	12
Total	-	26 weeks	78 sessions

Supplementary Table 5-8. Match exposure hours calculations for sub-elite women's cricket

Matches	Matches played (per team)	All matches played (all teams)	Total exposure hours per match per team	Total exposure hours for all teams for the season
20 overs	10	30	14.7	441
50 overs	10	30	43.3	1299
All matches	20	60	-	1740 hours

Supplementary Table 5-9. Training exposure hours calculations for sub-elite women's cricket

Training	Duration of session	Total sessions over the season	Total exposure hours per player	Total exposure hours (all teams)
Net session & strength and conditioning	2hrs	24 sessions	6hrs x 24 sessions	144 hours per player x 44 players
Net session & fielding	2hrs			
Net session	2hrs			
Total	6hrs	24 sessions	144 hours	6336 hours

CHAPTER 6. ANTHROPOMETRIC AND BIOMECHANICAL FACTORS IN ELITE MALE AND FEMALE FAST BOWLERS

The aims and objectives of this chapter are presented **in Ch. 1, pg. 4.**

This chapter is presented as a manuscript of an article under the second round of peer-review in Journal of Biomechanics.

PAPER 4

Anthropometric and Biomechanical Factors in Elite Male and Female Fast Bowlers

Jolandi Jacobs, Benita Olivier, Corlia Brandt, Nathanael Boulle

Abstract

Objectives: This study described and compared the anthropometric qualities and bowling biomechanics between elite male and female fast bowlers.

Methods: An inertial measurement system was used to collect three-dimensional biomechanical data for 20 elite fast bowlers (13 males and seven females). Kinematic data was captured from one step before back foot contact, back foot contact, front foot contact, ball release to one step after ball release. Anthropometric measurements included body segment lengths, mass, body fat (BF%) and muscle mass (MM%). Levene's Test for Equality of Variances was used to compare means. The student t-test and Mann-Whitney U test were used for analyses. Hotelling's T2 statistic was calculated to control Type I error between the two sexes for differences in biomechanics (p=0.045).

Results: Males and females differed in overall height, limb length, BF% and MM%. Females presented with slower ball release speeds (p=0.001). Biomechanically, the females were more front-on when approaching the delivery stride and then initiated pelvis and trunk rotation during the delivery stride, not seen in the males. Females and males have a similar magnitude of trunk side flexion, but females present with a different strategy than males (p=0.038). Females presented with increased front knee extension at ball release (p=0.05).

Conclusion: The findings from this study emphasise the differences between male and female fast bowlers and suggest that the coaching principles used in male fast bowling may not be relevant to female fast bowlers.

Anthropometric and Biomechanical Factors in Elite Male and Female Fast Bowlers

Jolandi Jacobs, Benita Olivier, Corlia Brandt, Nathanael Boulle

6.1 Introduction

The performance of fast bowlers is mainly linked to their ball release speed, as increasing ball release speed increases the difficulty for batters to score runs or defend their wicket. Hence, fast bowlers and their coaches constantly try to increase ball release speed by addressing kinematics and bowling techniques (Worthington et al., 2013b). Research on fast bowling biomechanics and anthropometrics in men's cricket (Wormgoor et al., 2010; Portus et al., 2004; Glazier et al., 2000; Worthington et al., 2013b) is widely researched. Still, the same cannot be said for female fast bowling.

Several studies have investigated the relationship between biomechanics and ball release speed in men's cricket (Wormgoor et al., 2010; Portus et al., 2004; Glazier et al., 2000). In the last decade, research on male fast bowling indicates that ball release speed is linked to faster run-up speeds (Worthington et al., 2013c; Kiely et al., 2021), reduced time at the back foot contact (BFC) (Kiely et al., 2021), braced front knee during front foot contact (FFC) (Worthington et al., 2013b), greater trunk flexion and delayed onset of shoulder counter-rotation (Worthington et al., 2013b). Besides kinematic factors in male fast bowlers, anthropometric qualities also play a role in ball release speed. Previous research (Glazier et al., 2000) suggests increased shoulder-to-wrist and total arm length may be associated with increased ball release speed in

male fast bowlers. However, recent studies suggest that no single anthropometric characteristic or body somatotype variable influences the ball release speed of male fast bowlers (Salter et al., 2007; Wormgoor et al., 2010).

Bowling biomechanics are found to be different between male and female fast bowlers, and it could be the cause for the slower ball release speeds seen among females (Felton et al., 2019). Research on female fast bowling indicates that females generally have shorter run-ups than male fast bowlers, resulting in slower ball release speeds (Savage and Portus, 2002a; Lucente et al., 2021). More recently, Felton et al. (2019) discovered that female fast bowlers have slower run-up speeds and less whole-body momentum, resulting in a slower ball release speed and biomechanical differences compared to male fast bowlers. Felton et al. (2019) indicated that female fast bowlers use more thoracic and pelvis rotation to compensate for the loss of whole-body momentum.

Besides bowling biomechanics, anthropometric qualities are also unique for female fast bowlers. According to Savage and Portus (2002) female fast bowlers have slower ball release speeds than their male counterparts due to shorter upper and lower limb lengths and lower muscle strength. Stuelcken et al. (2007) suggested that female fast bowlers had slower ball release speed than males due to the more endomorphic body build than males' mesomorphic body type. (Letter et al., 2022a) further indicated that ball release speed is affected by lower and upper body strength in female fast bowlers. The findings above suggest that certain factors influencing bowling performance are sex independent, with implications for both male and female fast bowlers.

There is still a significant gap in scientific knowledge around female fast bowlers' biomechanical technique and factors contributing to ball release speed. It is unknown if the knee angle at FFC indicates increased ball release speed for females as it is for males or if shoulder counter-rotation affects the ball release speed in female cricket players. There is limited research investigating if shorter limb lengths or body types are associated with reduced ball release speeds in females compared to males. This study will shed light on the potential anthropometric and biomechanical factors contributing to differences in fast bowling performance between elite male and female cricket players. Understanding these differences could lead to a more individualised approach, including more tailored training programs for both male and female fast bowlers, promoting sex-specific sports advancements. To gain a better insight into the biomechanics and anthropometric qualities of female fast bowlers, we aim to compare the differences between elite male and female fast bowlers in South Africa.

6.2 Methods

6.2.1 Study design and setting

This was a cross-sectional, quantitative study. Data collection occurred at the respective cricket unions during the 2022/2023 season for elite male and female fast bowlers.

6.2.2 Participants

Elite male and female fast bowlers were recruited from the elite fast bowling cohort of Cricket South Africa (CSA). Twenty injury-free bowlers, 13 male and seven female fast bowlers, agreed to participate in this study. CSA's Medical Research Committee permission and the Human Research Ethics Committee (Medical) of the University of the Witwatersrand granted ethical approval. Before the start of the study, all participants and guardians of those under the age of 18 provided written consent for using their data in this study.

6.2.3 Instrumentation and outcome measures

The researchers gathered 3D biomechanical data using an inertial measurement unit (IMU) and an analysis system. The Xsens (MVN Link Biomech, Xsens Technologies B.V., Enschede, Netherlands) system consists of a full-body human measurement system recording at 240 Hz using biomechanical models and sensor integration algorithms. The Xsens hardware comprises a lycra suit with markers for each of the 17 inertial measurement unit (IMU) sensors (Roetenberg et al., 2013). The MVN Analyse software was utilised to capture biomechanical data, which was subsequently synchronised by an algorithm into corresponding joint and segment angles. A comparison was made between the joint angles in the sagittal plane and non-sagittal torso-related angles obtained from Xsens MVN and those obtained from a 3D marker-based motion capture system. Xsens is a validated biomechanical system (Zhang et al., 2013), and a pilot study was conducted prior to the initiation of the present study.

6.2.4 Data collection

Anthropometric measurements were taken before the commencement of the biomechanical analysis. First, the anthropometrics measurement was conducted per the calibration requirements of the Xsens system. The metrics represent the overall stature of an individual, comprising the total height, shoulder height, shoulder width, arm span, hip height, hip width, knee height, ankle height, shoe height, and foot length. A detailed description of the metrics is provided in **Ch. 6 Suppl. Table 6-1**. The body measurements were then logged into the Xsens software. Secondly, body composition measurements were taken on the Omron (Model OM-BF511) body composition scale (Omron BF306, Omron Healthcare, Inc., Vernon Hills, IL) (Lintsi et al., 2004). Data from the scale comprised various measurements such as mass, body mass index (BMI), body fat percentage, muscle mass percentage, and resting metabolic rate (RMR).

Before conducting the 3D bowling analysis, all participants were directed to engage in a complete warm-up routine similar to a match warm-up. Subsequently, the bowler then put the lycra suit on. The IMUs were connected and calibrated in the N-pose (arms neutral alongside the body) and walking as an activity (Roetenberg et al., 2013). After a successful calibration, the bowlers were instructed to bowl six deliveries at match speed with a 156g cricket ball for males and a 142g ball for females. Bowling accuracy was measured using a target behind the wickets as used by (Portus et al., 2000). The velocities at which the bowlers released the balls were recorded using a radar gun (Stalker ATS®, Texas, USA) that was situated 180° behind the ball release

point. The Xsens software was utilised to capture three-dimensional biomechanical data during the trials.

6.2.5 Data reduction and statistical analysis

Ninety-eight bowling trials (61 for males and 37 for females) were successfully extracted from the Xsens software. The data analyst calculated the biomechanical angles for all bowling trials according to the definitions and movement planes (**Table 6-1**) in MATLAB (v 2022b, MathWorks, Natick, MA). Key segments of each bowling trial were identified for analysis, i.e. one step before back foot contact, back foot contact (BFC), front foot contact (FFC), ball release (BR) and one step after ball release (**Fig. 6-1**).

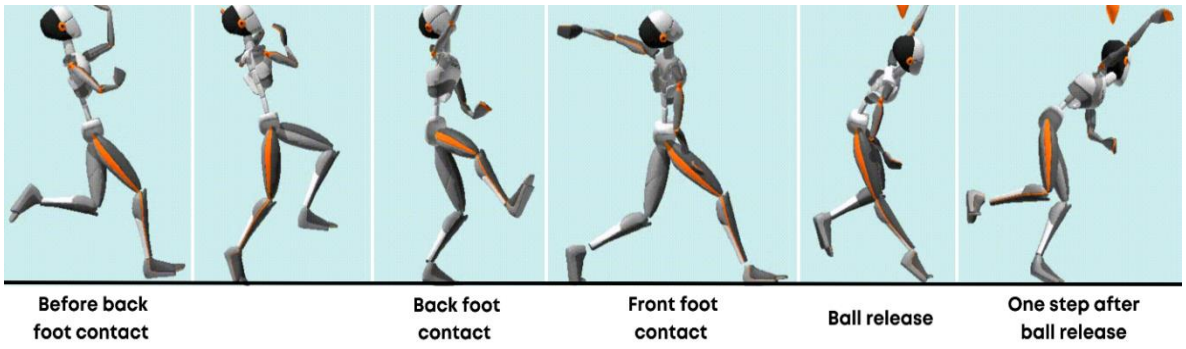


Figure 6-1: Each time point of the fast bowling action

Before-BFC was defined as the time interval of 100 timesteps (100hz) from before-BFC and identified the maximum combined acceleration of the front leg in the interval. BFC was identified as occurring four frames (0.017 s) before the peak resultant back tibial acceleration that occurred within 100 frames (0.42 s) prior to front foot contact

(Olivier et al., 2023a; Lamb et al., 2022). FFC was identified as occurring three frames (0.013 s) before the peak resultant front tibial acceleration that occurred within 300 frames (1.25 s) prior to the overall (for the trial) peak resultant forearm acceleration. BR was identified as occurring at the instant of the peak resultant bowling forearm acceleration that was recorded within 50 frames (0.21 s) after front foot contact (Olivier et al., 2023a; Spratford et al., 2015). One step after BR was identified as five frames (0.021 s) occurring before the peak resultant back tibial acceleration that occurred within 125 frames (0.52 s) after ball release (Olivier et al., 2023a). The BFC phase was defined as beginning at BFC and ending at FFC. The FFC phase was defined as beginning at FFC and ending at BR. The follow-through phase began at BR and ended at the one step after BR. The total movement was defined as the sum of these three phases. Three-dimensional data time stamps for each segment mentioned above were extracted for further data analysis. Definitions for each biomechanical plane are listed in **Table 6-1**.

All statistical analyses, including means, data distribution (standard deviation (SD)), standard error, and significance, were carried out using SPSSv.28 (SPSS Corporation, USA). The trials for each player were grouped, and a mean for each player (13 males and seven females) was calculated. The means of the trials for each player reduced the standard error during the analyses. The data were assessed for normality using Levene's Test for Equality of Variances to compare means. Hotelling's T^2 statistic was calculated to control Type I error between the two sexes for differences in biomechanics ($p=0.045$). The student t-test was used to analyse the independent

Table 6-1: Definitions of biomechanical variables

Biomechanical variable	Definition	Xsens MVN System movement variable*
Time duration	The measurable length of a phase of the bowling action.	N/A
Trunk side flexion	The biomechanical variable represents the lateral bending of the trunk. The trunk is the segment between the shoulders (C7 or T1) and L5. Trunk side flexion to the left was captured as negative degrees, and to the right, it was positive.	Joint Angles ZXY or XZY was used to capture trunk side flexion. The rotation around the Z-axis (for ZXY) or X-axis (for XZY) represented trunk side flexion.
Trunk rotation	The axial turning of the trunk relative to the pelvis. The trunk is defined as the segment between the shoulders (C7 or T1) and L5, and this rotation is also referred to as the pelvis-shoulder separation angle.	Joint Angles ZXY or XZY was used to capture trunk rotation. The rotation around the Y-axis (for both ZXY and XZY) represented trunk relative to the pelvis.
Pelvis rotation	The rotational movement of the pelvis relative to the lower back (L5).	Joint Angles ZXY or XZY was used to capture pelvis rotation. The rotation around the Z-axis (for ZXY) or X-axis (for XZY) represented the rotational movement of the pelvis.
Centre of mass	The centre of mass is a point within the pelvis representing the average location of the body's mass.	N/A
Hip flexion and extension	The biomechanical movements of the hip joint that involve a decrease (flexion) or an increase (extension).	Joint Angles ZXY or XZY was used to capture hip flexion and extension. The rotation around the Y-axis (for both ZXY and XZY) represented hip flexion and extension.
Knee flexion and extension	The biomechanical movements of the knee joint that involve a decrease (flexion) or an increase (extension).	Joint Angles ZXY or XZY was used to capture knee flexion and extension. The rotation around

Biomechanical variable	Definition	Xsens MVN System movement variable*
		the Y-axis (for both ZXY and XZY) represented knee flexion and extension.
Ball release speed	The velocity at which the cricket ball is released during the bowling action.	N/A
Shoulder counter rotation	The transverse clockwise movement (away from the batter) of the shoulder alignment was recorded between back foot and front foot contact.	Joint Angles ZXY or XZY was used to capture shoulder counter rotation. The rotation around the Z-axis (for ZXY) or X-axis (for XZY) represented the transverse movement of the shoulder alignment.

variables, and if any parameters violated the normality assumption, the non-parametric Mann-Whitney U test was conducted instead. Cohen's d and η^2 classification were used to determine the effect sizes of parametric and non-parametric tests, respectively. The effect sizes were grouped as small effect sizes <0.2, medium 0.2-0.8, and large >0.8, indicating the strength of the relationship or the practical significance of the observed effect. The anthropometric values were standardised using z-score normalisation, subtracting the mean and dividing by the standard deviation to transform each value. The distribution has a mean of 0 and a standard deviation of 1.

Table 6-2: Group means and differences of body measurements and anthropometric qualities for elite male and female fast bowlers

Variables	Female Mean (SD)	Male Mean (SD)	Mean Difference (SE)	Normalisation		P-value	Effect sizes
				Female Mean (SD)	Male Mean (SD)		
Age (years)	22.86 (3.93)	23.77 (3.68)	0.91 (1.77)	-0.62 (3.93)	0.48 (0.75)	0.612	0.24
Mass (kg)	67.30 (11.37)	81.82 (11.21)	14.52 (5.28)	-0.91 (0.83)	0.92 (0.76)	0.013	1.29
Height (m)	165.50 (9.04)	184.77 (7.58)	19.27 (3.80)	-1.64 (0.73)	1.62 (0.68)	0.481	2.38
BMI (kg/m^2)	24.97 (2.49)	24.45 (2.47)	0.52 (1.16)	0.26 (0.77)	-0.26 (0.77)	0.661	0.21
Body fat %	35.46 (5.70)	19.36 (7.26)	16.10 (3.18)	1.15 (0.86)	-1.15 (1.00)	<0.001	2.37
Muscle mass %	26.41 (1.97)	39.84 (4.20)	13.42 (1.69)	-1.38 (0.89)	1.38 (0.95)	<0.001	3.72
RMR (kcal)	1381.86 (154.55)	1804.54 (137.20)	422.68 (67.14)	-1.50 (0.91)	1.50 (0.85)	<0.001	2.95
Shoulder height (mm)	141.71 (8.83)	158.46 (6.17)	16.75 (3.36)	-1.61 (0.83)	1.61 (0.80)	<0.001	2.34
Shoulder width (mm)	38.57 (1.27)	41.54 (2.73)	2.97 (1.10)	-1.54 (0.85)	1.54 (0.89)	0.015	1.27
Arm span (mm)	167.64 (8.29)	187.77 (5.31)	20.13 (3.03)	-1.55 (0.84)	1.55 (0.87)	<0.001	2.99
Hip height (mm)	87.64 (6.39)	101.46 (5.30)	13.82 (2.67)	-1.63 (0.83)	1.63 (0.87)	<0.001	2.43
Hip width (mm)	23.86 (1.35)	28.15 (2.44)	4.30 (1.00)	-1.70 (0.85)	1.70 (0.87)	<0.001	2.01
Knee height (mm)	46.07 (3.52)	52.46 (3.67)	6.39 (1.70)	-1.39 (0.84)	1.39 (0.85)	<0.001	1.77
Ankle height (mm)	7.43 (2.76)	11.62 (1.33)	4.19 (0.90)	-1.07 (0.86)	1.07 (0.86)	<0.001[b]	0.68*
Shoe height (mm)	2.93 (0.19)	3.23 (0.44)	0.30 (0.18)	-1.54 (0.76)	1.54 (0.91)	0.08[b]	0.16*
Foot length (mm)	27.86 (1.57)	29.38 (1.04)	1.53 (0.58)	-1.59 (0.87)	1.59 (0.87)	0.018	1.23

*[a]t-test, [b]Mann-Whitney U test. Effect sizes were calculated by Cohen's d (parametric) and *η^2 (non-parametric).*

6.3 Results

6.3.1 Participant characteristics

Seven female fast bowlers and 13 male fast bowlers with a mean (SD) age of 22.86 (3.93) years for females and 23.77 (3.68) years for males participated in this study. All 20 participants were right-handed fast bowlers.

6.3.2 Anthropometric qualities

Anthropometric measurements are indicated in **Table 6-2**. Significant differences were found for the following variables: mass, height, BF%, MM% and RMR. Males had increased body measurements with larger effect sizes compared to females.

6.3.3 Bowling biomechanics

The bowling biomechanics data are indicated in **Table 6-3**. Males had increased ball release speed compared to females. Females took more time than males for all phase lengths from one bowling phase to another (**Fig. 6-2 A**). At before-BFC female fast bowlers presents with reduced trunk and pelvis rotation and decreased hip and knee flexion of the front leg (**Fig. 6-2 C-H**). There were differences at BFC for trunk side flexion (**Fig. 6-2 B**) and knee flexion of the back leg (**Fig. 6-2 H**). At FFC, females had longer phase lengths to ball release than males. Females also had reduced trunk side flexion and knee flexion of the back leg, while males had increased knee flexion of the

front leg. At BR, females presented with reduced knee flexion of the front leg compared to males (**Fig. 6-2 G**). At one step after BR, females showed increased trunk and pelvis rotation compared to males. Females had increased hip flexion and decreased knee flexion of the front leg compared to males (**Fig. 6-2 E and G**).

6.4 Discussion

This study aimed to describe and compare the anthropometric qualities and bowling biomechanics of female fast bowlers, highlighting distinctions from male counterparts to emphasise the need for a unique approach when working with female players. The unique biomechanical and anthropometric discrepancies can be further investigated to guide coaches to implement individualised training techniques for female fast bowlers, as the coaching strategies used for male fast bowlers cannot be replicated for females.

The anthropometric variables between males and females displayed several key observations. Notably, the variables related to body composition, such as BF%, MM% and RMR, show substantial differences between the two sexes. Females exhibited higher body fat percentages and lower muscle mass percentages compared to males. Additionally, the RMR is significantly lower in females. Furthermore, height-related variables, such as shoulder height, arm span, hip height, and knee height, all demonstrate considerable distinctions, with males consistently displaying larger measurements. These findings underscore the importance of considering sex-specific

Table 6-3: Group means and standard deviation of biomechanical variables for elite male and female fast bowlers

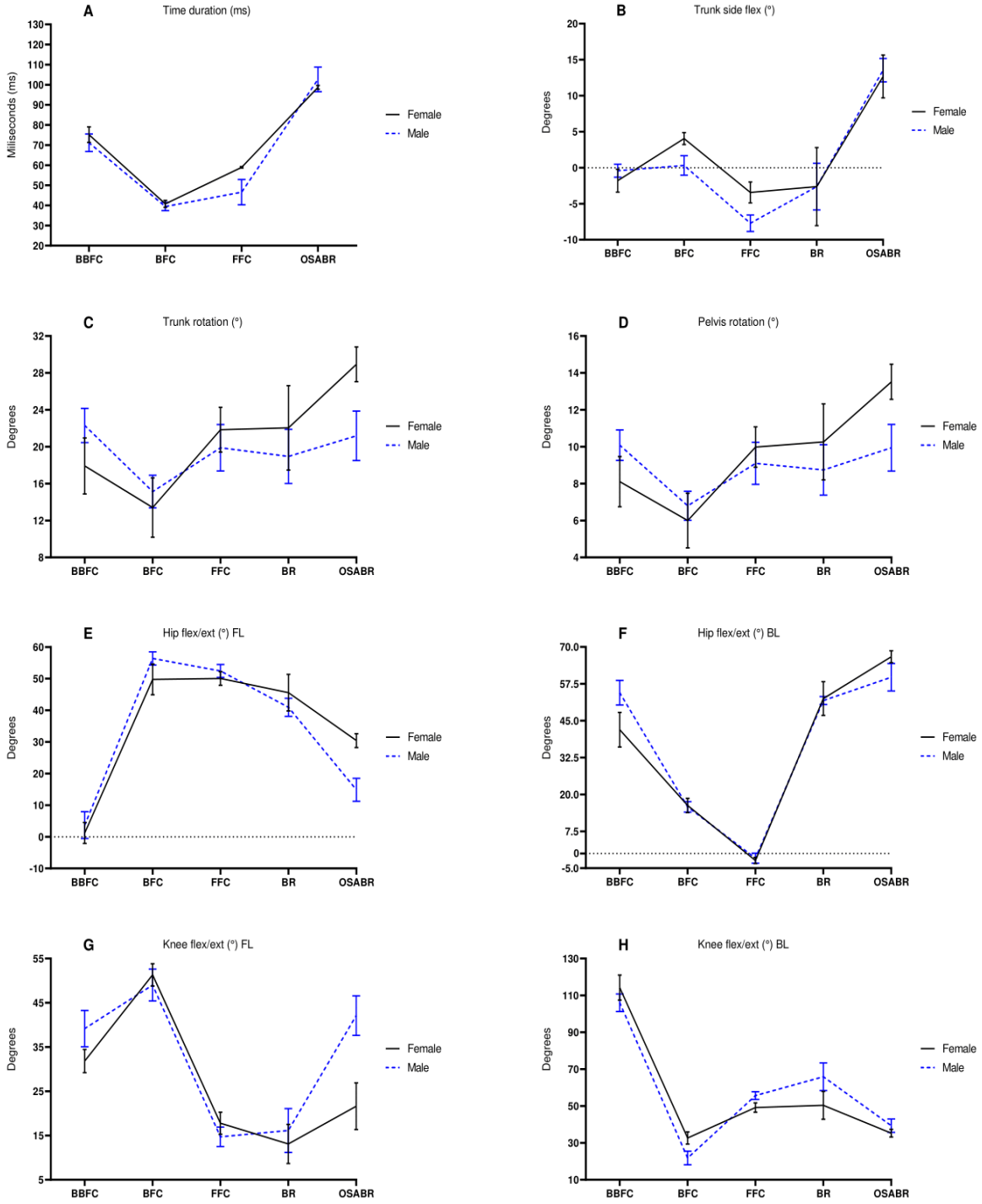
Variables	Before-BFC				BFC				FFC			
	Female Mean (SD)	Male Mean (SD)	P-value	Effect sizes	Female Mean (SD)	Male Mean (SD)	P-value	Effect sizes	Female Mean (SD)	Male Mean (SD)	P-value	Effect sizes
Time duration (ms)	75.17 (10.15)	71.13 (15.80)	0.551[a]	0.20	40.78 (4.60)	39.42 (7.33)	0.664[a]	0.28	58.90 (20.98)	46.59 (22.60)	0.250[a]	0.56
Trunk side flex (°)	-1.8 (4.19)	-0.41 (3.26)	0.420[a]	0.39	4.04 (2.21)	0.31 (4.88)	0.073[a]	0.89	-3.44 (3.83)	-7.71 (4.16)	0.038[a]	1.05
Trunk rotation (°)	17.92 (8.06)	22.30 (6.68)	0.209[a]	0.61	13.40 (8.51)	15.14 (6.39)	0.612[a]	0.24	21.84 (6.41)	19.88 (9.11)	0.621[a]	0.24
Pelvis rotation (°)	8.11 (3.60)	10.08 (2.99)	0.205[a]	0.62	6.00 (3.92)	6.80 (2.84)	0.604[a]	0.25	9.98 (2.89)	9.10 (4.11)	0.658[a]	0.21
COM (m)	1.02 (0.47)	1.11 (0.17)	0.208[a]	0.61	0.98 (0.05)	1.12 (0.04)	<0.001[a]	3.11	0.84 (0.04)	0.97 (0.08)	0.001[a]	1.80
Hip flex/ext (FL) (°)	1.21 (8.77)	3.68 (15.21)	0.699[a]	0.18	49.77 (12.93)	56.40 (7.52)	0.160[a]	0.69	50.04 (5.70)	52.41 (7.44)	0.474[a]	0.34
Hip flex/ext (BL)(°)	41.96 (15.59)	54.49 (15.09)	0.097[a]	0.82	16.25 (6.40)	15.78 (6.40)	0.879[a]	0.07	-2.41 (2.79)	-1.62 (6.19)	0.754[a]	0.15
Knee flex (FL) (°)	31.82 (6.92)	39.16 (14.83)	0.501[b]	0.02*	51.32 (6.68)	49.01 (13.01)	0.722[a]	0.17	17.76 (6.64)	14.70 (7.94)	0.398[a]	0.41
Knee flex (BL) (°)	114.24 (18.06)	106.01 (17.32)	0.331[a]	0.47	32.64 (8.78)	21.76 (13.39)	0.070[a]	0.90	49.16 (6.76)	55.67 (7.58)	0.074[a]	0.89

Back foot contact (BFC), front foot contact (FFC), ball release (BR), front leg (FL), back leg (BL), flexion (flex), extension (ext).
*[a]t-test, [b]Mann-Whitney U test. Effect sizes were calculated by Cohen's d (parametric) and *η^2 (non-parametric).*

Table 6-3 (cont.): Group means and standard deviation of biomechanical variables for elite male and female fast bowlers

Variables	BR				One step after BR			
	Female Mean (SD)	Male Mean (SD)	P-value	Effect sizes	Female Mean (SD)	Male Mean (SD)	P-value	Effect sizes
Time duration (ms)					98.69 (12.54)	102.68 (22.12)	0.613[a]	0.21
Trunk side flexion (°)	-2.62 (14.34)	-2.62 (11.72)	1.000[a]	0.00	12.67 (7.84)	13.54 (5.88)	0.782[a]	0.13
Trunk rotation (°)	22.04 (12.12)	18.95 (10.58)	0.560[a]	0.28	28.93 (4.99)	21.18 (9.69)	0.104[b]	0.14*
Pelvis rotation (°)	10.26 (5.45)	8.74 (4.93)	0.533[a]	0.30	13.52 (2.53)	9.94 (4.56)	0.037[a]	0.89
COM (m)	0.87 (0.06)	1.00 (0.08)	0.002[a]	1.70	0.85 (0.06)	0.99 (0.08)	0.002[a]	1.71
Hip flex/ext (FL) (°)	45.55 (15.37)	40.92 (10.37)	0.431[a]	0.38	30.40 (5.82)	14.86 (13.19)	0.008[b]	0.37*
Hip flex/ext (BL) (°)	52.51 (15.13)	51.82 (14.88)	0.878[a]	0.07	66.67 (5.44)	59.75 (16.75)	0.192[a]	0.49
Knee flexion (FL) (°)	13.09 (11.71)	16.13 (19.49)	0.050[a]	0.27	21.61 (13.97)	42.09 (16.1)	0.011[a]	1.33
Knee flexion (BL) (°)	50.36 (20.11)	65.89 (27.19)	0.166[a]	0.62	35.26 (5.50)	39.32 (13.17)	0.451[a]	0.36
Ball release speed (km/h)	101.30 (5.63)	131.90 (5.11)	<0.001[a]	5.78				
Shoulder counter rotation (°)	21.46 (15.57)	12.25 (9.16)	0.191[b]	0.09*				

Back foot contact (BFC), front foot contact (FFC), ball release (BR), front leg (FL), back leg (BL), flexion (flex), extension (ext).
*[a]t-test, [b]Mann-Whitney U test. Effect sizes were calculated by Cohen's d (parametric) and *η^2 (non-parametric).*



Before back foot contact (BBFC), back foot contact (BFC), front foot contact (FFC), ball release (BR), one step after ball release (OSABR), front leg (FL), back leg (BL), flexion (flex), extension (ext).

Figure 6-2: Line graphs of biomechanical comparisons between elite male and female fast bowlers

variations in anthropometric characteristics and suggest potential areas for targeted interventions or further investigation. Although these differences between males and females are not unique to cricket players (Santos et al., 2014), they may influence the ball release speed attained during the bowling action. Previous researchers discovered strong correlations between arm length and overall body mass, leading to increased ball release speed in men's cricket (Glazier et al., 2000; Pyne et al., 2006).

Analyses of body compositions in this study indicated high BF% and low MM% for female fast bowlers. These findings are similar to previous research on elite fast bowlers, where females were more endomorphic and less mesomorphic than males (Stuelcken et al., 2007). Savage and Portus (2002a) suggested that female bowlers have reduced muscle strength and shorter upper limbs, which could be linked to slower ball release speeds compared to males. Future research should investigate if the differences in anthropometric measurements, such as arm span, hip height and overall height, BF% and MM%, could be a factor for the biomechanical differences we observe in female fast bowlers.

The female fast bowling biomechanics in this study vary from the male fast bowlers. Female fast bowlers presented with longer phase lengths from before-BFC to one step after BR, which indicates reduced linear momentum for female fast bowlers as they progress through the delivery stride. Another finding at before-BFC indicated that females presented with reduced hip flexion of the back leg, which could be linked to the reduced linear momentum generated in their bowling action. Notably, males, leveraging increased hip flexion of the back leg, stride forward to BFC with more linear

momentum. In contrast, females in this study demonstrate slower ball release speeds (101.30 ± 5.63 km/h) than their male counterparts. This divergence challenges conventional expectations, as previous research has often suggested that female fast bowlers adopt techniques resembling those of their male counterparts. Contrary to this expectation, our findings align with Savage and Portus (2002a) who found that female fast bowlers have slower run-ups than males and findings by Felton et al. (2019) that females have less linear momentum as they approach the delivery. Thus, our findings are similar to previous research suggesting that female fast bowlers have reduced linear momentum during the delivery stride and reduced ball release speeds compared to male fast bowlers (Felton et al., 2019).

This study identified that females initiated more trunk and pelvis rotation during their bowling action. Females initially presented with lower pelvis and trunk rotation compared to males at the point of before-BFC, indicating a front-on approach for females as they approach the delivery stride. The females then present with more trunk and pelvis rotation at the phase length from BFC to FFC. It is also interesting to note that the females' phase lengths from BFC to FFC longer than males. The additional time available can be utilised to generate rotation in the trunk and pelvis. No significant increase in trunk or pelvis rotation or trunk side flexion was observed during FFC to BR. During BR to one step after BR females present with increased rotation of the trunk and pelvis compared to males. This could be because of the transverse momentum generated in the BFC to FFC, which is now causing the transverse momentum to push the females into further rotation after the delivery stride, similar to a wind-up and wind-down effect. Felton et al. (2019) suggested that females have less

linear momentum when arriving at the crease and compensate by using a biomechanical pattern during the delivery stride, using large rotator muscles to generate momentum. Similar to these findings, the females in our study could use the increased rotational strategies to increase transverse momentum during their delivery stride.

There were notable biomechanical differences between male and female fast bowlers at the front leg. Males presented with increased hip flexion of the front leg at BFC and decreased hip flexion at BR (**Fig. 6-2 E**) compared to females. This finding suggests that males use more hip extension of the front leg from BFC to BR, indicating that males rely on the flexion to extension movement of the front hip compared to females who maintain somewhat of a similar magnitude of hip flexion from BFC to BR. Felton et al. (2019) also noted a difference in timing in hip extension between male and female fast bowlers but at the back leg. Further research is warranted to investigate if the magnitude of hip flexion/extension is a performance factor for female fast bowling, as this differs from the action we see in males. Another difference was noted at the knee joint of the front leg. Females presented with decreased knee flexion from FFC to BR compared to males, who presented with increased knee flexion from FFC to BR. Females also presented with reduced front knee flexion (more extended knee) at BR compared to males. It could be suggested that the females in our study used a knee extension technique at the front leg from FFC to BR (**Fig. 6-2 E**). In contrast to males who used a hip extension technique of the front leg from BFC to BR (**Fig. 6-2 G**). A straighter knee throughout the front foot contact phase is associated with faster ball release speeds (Worthington et al., 2013b). However, Olivier et al. (2016) found that

bowlers can potentially enhance their BR speed and remain injury-free over a season by maintaining a flexed knee throughout the bowling action. Future studies should investigate the knee angles of the front leg at FFC and BR and the association with ball release speed and knee injury risk in female fast bowlers.

A noteworthy finding of this study was the disparity in trunk side flexion between males and females (**Fig. 6-2 B**). Females presented with trunk side flexion to the left compared to a neutral (upright) trunk position of the males before-BFC. Females then transition to side-flexion to the right, whereas males maintain a neutral (upright) trunk at BFC. Males and females present with increased trunk side flexion towards the left at FFC. Interestingly, the magnitude of left trunk side flexion from BFC to FFC was similar for both genders. However, males exhibited an augmented total magnitude of right-side trunk side flexion at FFC due to their neutral (upright) trunk position at BFC, in contrast to females who initially presented with left side trunk flexion at BFC. This technique could be beneficial for the females as previous research indicated that female fast bowlers had proportionally longer trunk lengths than male fast bowlers (Stuelcken et al., 2007) and could be an anthropometrical and biomechanical advantage for the females to use right to left trunk side flexion to generate momentum during the delivery stride. The rate of lower back injuries among female fast bowlers is lower than that of males (Jacobs et al., 2022). Further research should explore whether the initial right trunk flexion at BFC could be a contributing factor to the reduced occurrence of lower back injuries in females. Lower back injury rates in female fast bowlers are less than for males and future research should investigate if the initial right trunk flexion at BFC could be advantageous and a factor in why females have

reduced lower back injury. Future research should investigate a larger sample size of female fast bowlers to investigate their trunk side-flexion strategy, whether this is an increased ball release speed strategy in females, and the effect on injury risk in fast bowlers.

Females in this study presented with higher shoulder counter-rotation than males. The high degrees of shoulder counter-rotation could aid in the transverse momentum generated during the delivery stride. Felton et al. (2019) suggested that female fast bowlers rotate, using the shoulder, trunk, and pelvis during their bowling stride, similar to a throwing technique. This rotational bowling technique could benefit females by generating more momentum to increase ball release speed, but the high shoulder injury rates in female fast bowlers are a concern (Jacobs et al., 2022). Future research should investigate the trade-off between the high degrees of shoulder counter-rotation for bowling performance and the increased risk of shoulder injury associated with this technique. Coaches and clinicians working with female fast bowlers should focus on strengthening the shoulder muscles for improved performance and injury prevention.

A limitation of this study is the small population of elite female fast bowlers, however, still a big sample compared to the entire population. Future research should investigate a larger cohort of elite female fast bowlers, the relationship between musculoskeletal, anthropometrics and bowling biomechanics, and how these factors could influence ball release speed and injury risks. A strength of this study is the use of IMU, as the players could be exposed to an outdoor pitch and environment, which aided the ecological validity as it was closer to match and training circumstances than

testing them in laboratories on a different surface. Also, reporting the before-BFC and one step after BR is a strength of this study, as the fast bowling action should be assessed holistically, not just the phase length from BFC to BR. Future studies should include before-BFC as part of their bowling analyses. This segment predicts the setup of kinematics at the BFC, and the phase length from before-BFC to BFC is an essential technique coaches reinforce in their bowlers during coaching sessions.

6.5 Conclusion

This study suggests that female fast bowlers have unique anthropometry and bowling biomechanics. Female fast bowlers spend longer in the phase lengths through the delivery stride, specifically from BFC to FFC. Females have increased pelvis and trunk rotation from BFC to FFC and BR to one step after BR and increased total shoulder counter-rotation. A novel finding of this study is that females use a different trunk side flexion strategy compared to males from before-BFC to FFC. Further, the extended time of the phase length through the delivery stride enables the female bowlers to use muscles working in the transverse plane to generate extra rotational momentum to increase ball release speed. Coaches should be aware of these strategies when altering bowling biomechanics in female fast bowlers. The current extrapolation of coaching strategies adopted from male fast bowling may not be relevant for females.

CHAPTER 7. DISCUSSION

7.1 Introduction

This thesis explored SSSM themes in female cricket players, contributing to existing knowledge and presenting novel findings on their physical profiles, injury incidence and bowling biomechanics. The thesis included four original papers, each contributing uniquely to the objectives outlined in **Ch. 1, pg. 4.**

Chapter 3, pg. 42 reviews applied SSSM research for female cricket players, summarising current findings while highlighting research gaps and priority areas. Chapters 4-6 aim to address some of these research gaps identified in Chapter 3. **Chapter 4, pg. 143** investigates the physical profiles of sub-elite female cricket players to establish baseline values for SSSM clinicians. **Chapter 5, pg. 174** provides insights into the injury profiles of sub-elite female cricket players. Finally, **Ch. 6, pg. 202** explores the bowling biomechanics of female pace bowlers, identifying similarities or discrepancies compared to male pace bowlers. This thesis provides novel findings for female cricket players and addresses the research gaps identified in **Ch. 3, pg. 42** offering evidence-based knowledge to guide future research and support applied SSSM clinicians.

7.2 Original contributions of this thesis

An updated conceptual framework is presented in **Fig. 7-1, pg. 226** and outlines the main findings from each study and how the studies address the original aims of this thesis (**Fig. 1-1, pg. 10**). The following aims and objectives were addressed in this thesis:

The scoping review in **Ch. 3, pg. 42** maps all available literature on SSSM for female cricket players. This review offers SSSM practitioners a summary of the current evidence-based findings applicable to female cricket players for implementation in clinical practice. Additionally, the review maps current literature and identifies priority research areas for women's cricket as presented in **Table 3-3, pg. 92.**

Chapter 4, pg. 143 presents novel findings on the physical profiles of sub-elite female cricket players. These original findings include providing baseline values for SSSM clinicians or researchers when testing other cohorts. This chapter identifies the unique physical profiles of each player role and the ratio deficits within each player role. This chapter also addressed a research gap identified in **Ch. 3, pg. 42** adding to the limited evidence on the physical profiles of female cricket players at the sub-elite levels. This chapter provides novel findings about the discrepancies in our cohorts, such as the deficit ratio of shoulder IR:ER in all-rounders, non-dominant muscle weakness in all player roles and the reduced musculoskeletal strength profile of bowlers compared to batters and all-rounders.

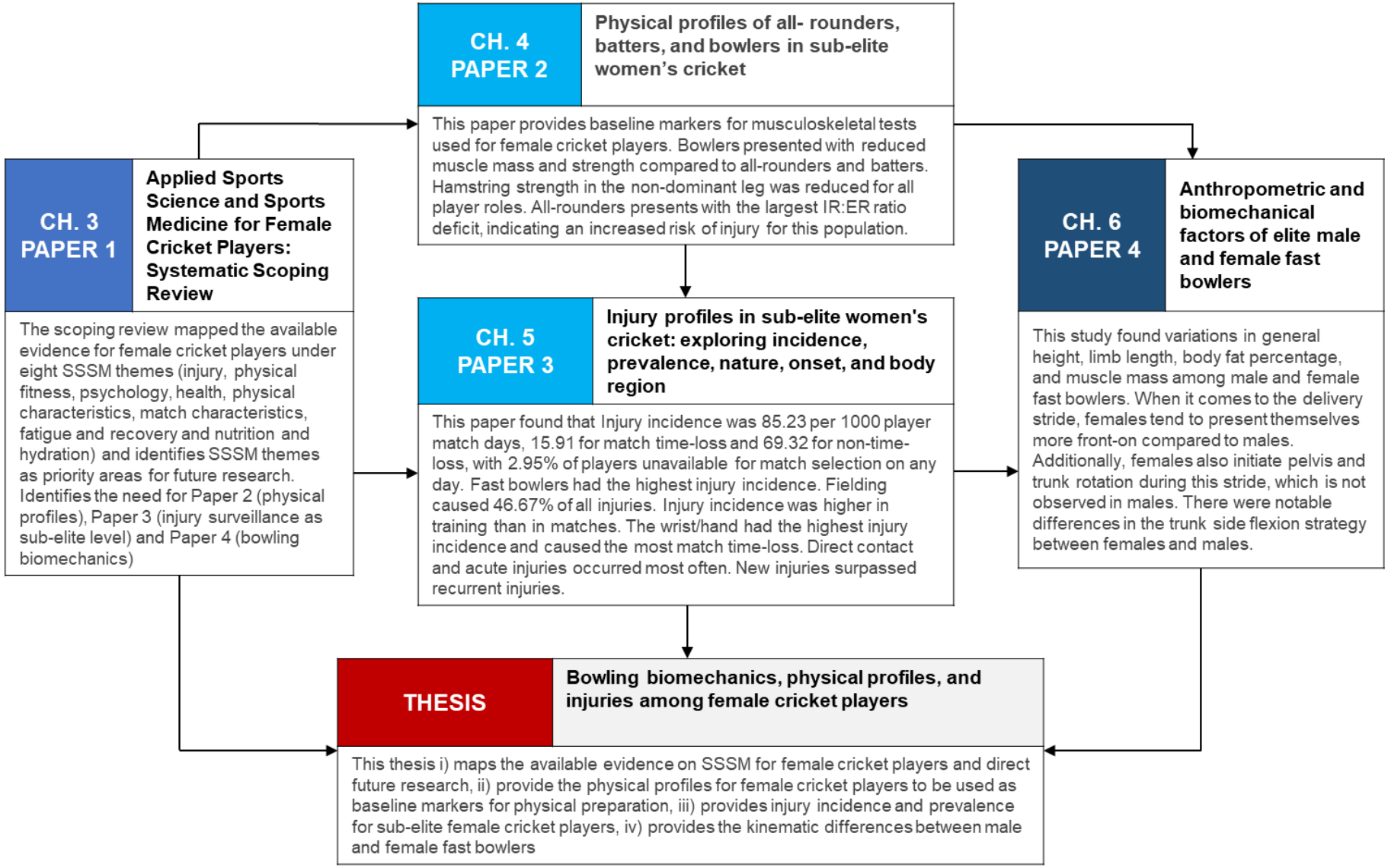


Figure 7-1: Key findings of the current thesis

Chapter 5, pg. 174 presents the incidence, onset, nature, and activity-related injuries among sub-elite female cricket players. The findings from this chapter are unique to the sub-elite level and address a critical gap in the literature identified in **Ch. 3, pg. 42**. This chapter further provides the injury rate (time-loss and non-time-loss) among sub-elite female cricket players, with pace bowlers identified as the players most prone to injury. Fielding was the activity that caused the most injuries irrespective of player role, resulting in a high incidence of direct injuries in this population. This information will guide SSSM researchers in investigating risk factors of direct contact injuries in female cricket players to guide clinicians in re-assessing current fielding strategies, such as catching and throwing techniques and safe grounding approaches, to reduce the high injury incidence observed in this population.

Chapter 6, pg. 202 investigated the bowling biomechanics of male and female pace bowlers to identify similarities or discrepancies between the sexes. This chapter describes the female bowling biomechanics, noting that females tend to adopt a more front-on action when arriving at the delivery stride than males. Additionally, females used a greater magnitude of rotational displacement in the trunk and pelvis and a different trunk side flexion strategy than males. The findings of this chapter will guide SSSM researchers to investigate the rotational strategies of female pace bowlers and assess the potential impact on ball release speed. Furthermore, the observed differences in trunk side flexion between males and females need to be investigated to determine whether the female bowling strategy might reduce the risk of back injuries commonly seen in male pace bowlers.

Finally, the findings from the physical profiles in **Ch. 4, pg. 143**, the injury profiles described in **Ch. 5, pg. 174** and biomechanical bowling action of pace bowlers in **Ch. 6, pg. 202** are further discussed to contribute to the current knowledge of female pace bowlers for SSSM researchers and clinicians.

This thesis explores female cricket players within the SSSM domain, providing a comprehensive map of current literature and guiding future research. Novel findings on injury and physical profiles of female cricket players include unique characteristics for each player role, the breakdown of the high incidence of direct contact injuries in fielding, and the identification of a unique trunk-side flexion strategy in female pace bowlers. The findings of this thesis will not only contribute significantly to the current knowledge of female cricket players and provide a narrative that will shape future research directions. Future research directions include prioritising female health considerations in line with injury and performance, encouraging further research to investigate fielding-related injuries, re-evaluating current fielding strategies, and investigating the trunk side flexion strategy used by female pace bowlers.

7.3 Physical profiles of female cricket players

Chapter 4, pg. 143 describes the physical profiles of female cricket players and the similarities and differences between each player's role. This objective links with the overall theme of the thesis to describe the physical profile of female cricket players. This chapter also presents novel findings on the physical profiles at the sub-elite level and the unique physical characteristics of each player role. The findings are discussed

under the following topics: body compositions, aerobic fitness, overall muscle strength, and the similarities and differences between the unique player roles.

7.3.1 Body composition

The body compositions of sub-elite female cricket players in **Ch. 4, pg. 153**, such as BMI, body mass, and MM%, fall within the healthy body mass category. This aligns with the profiles of prof6.1essional female athletes, as indicated by studies by Carbuhn et al. (2010), Vila et al. (2012) and Milanese et al. (2011). The body composition of the sub-elite female cricket players is also comparable to that of elite players, as reported by Stuelcken et al. (2007), Johnstone and Ford (2010) and Murphy et al. (2020). This discrepancy in fat percentage between sub-elite and elite levels highlights the higher physical demands expected at the elite level, emphasising the link between lower fat percentage and superior physical performance (Masanovic et al., 2019). The fat percentage difference between these levels suggests the higher physical demands expected at the elite level. Overall, our findings suggest that female cricket players at the sub-elite level present with body compositions near to similar to the elite level and suggestive of good physical fitness at the sub-elite levels. Similar player body compositions across different levels may stem from recent investments and enhanced professionalism in women's cricket, including the support of SSSM practitioners at the sub-elite level. These parallels between sub-elite and elite levels offer coaches and SSSM staff valuable insights into the specific requirements for players transitioning from sub-elite to elite levels.

While the body compositions in the sub-elite group were comparable to professional or elite female athletes, **Ch. 4, pg. 159-165** describes the notable differences between

the unique player roles within the sub-elite cohort. The body composition of players is expected to vary depending on their specific role in cricket (Weldon et al., 2021; Johnstone and Ford, 2010). All-rounders presented with the highest overall body mass, BMI and MM% compared with batters and bowlers. The higher body composition values seen in all-rounders are expected as these players must perform both their team's batting and bowling skills. As a result, the physical preparation for these players would require a combination of muscle strength, power and endurance, resulting in a higher body mass or BMI for optimal performance in their multifaceted roles. The higher body composition values of all-rounders align with their superior overall physical strength compared with batters and bowlers, as demonstrated in the battery of physical performance tests conducted in **Ch. 4, pg. 149.**

On the other hand, bowlers presented with the lowest body mass, RMR and MM% compared to other player roles. These findings align with elite men's cricket research, where bowlers presented with lower body mass than batters (Weldon et al., 2021). The physical characteristics seen in female bowlers could be an adaptation where bowlers rely on a combination of physical factors for performance, including the bowling run-up, explosive strength and biomechanical action, as opposed to batters and all-rounders who, in the context of batting skill, requires muscle power for achieving further hitting distances (Taliep et al., 2010).

Bowlers presented with the highest BF% compared to batters and all-rounders (**Ch. 4, pg. 156**). Stuelcken et al. (2007) found that female pace bowlers present with more subcutaneous adipose tissue and lower skeletal muscle than male bowlers. In men's

cricket, it has been found that improving muscle mass and decreasing body fat in bowlers can have a positive effect on their approach velocity during the run-up, resulting in a faster ball release speed (Pyne et al., 2006; Stuelcken et al., 2007). However, this is not a predictor of faster ball release speeds in females. The observed higher BF% among female bowlers in this study may indicate a preference for endurance training methods over explosive power training, typically favoured for batting skills. It is important to note that linking the higher BF% solely to endurance training is speculative. More research is needed to investigate female pace bowlers' body composition thoroughly and its impact on bowling performance when analysing body compositions, coaches, and SSSM practitioners working with various cricket player roles must consider the unique demands of each player position as well as the individual nutritional practices of each player.

7.3.2 Aerobic fitness

The aerobic fitness test in **Ch. 4, Suppl. Table 4-10, pg. 172** presents baseline values for sub-elite female cricket players. The 2km TT times in Paper 2 are slower than elite female cricket players (Letter et al., 2022a). Elite players will have superior aerobic performances compared to non-elite players due to the higher physical demands at the elite level (Masanovic et al., 2019). **Chapter 4, Table 4-1, pg. 156-158** present the differences in aerobic fitness levels among the player roles and found that batters performed better than all-rounders and bowlers. Johnstone and Ford (2010) suggested that batters may have higher aerobic fitness levels due to prolonged and continuous high intensity running between the wickets.

Drawing parallels, Castagna et al. (2009) found that explosive power accelerated the transition from eccentric to concentric contractions in basketball players, enhancing the overall distance covered and aerobic performance. As seen in this chapter, batters engage in prolonged and continuous bouts of high intensity running that impose a greater demand on aerobic fitness and explain why they performed better than bowlers and all-rounders. The superior aerobic fitness observed in batters is a possible adaptation to their specific role and could be an essential factor for physical conditioning. The findings from this chapter also propose a possible link between aerobic fitness and body composition in female batters, as batters presented with the lowest BF% compared to other player roles. While existing evidence supports the correlation between lower BF% and aerobic fitness in healthy adults (Shete et al., 2014), this correlation remains unexplored in cricket players. Further research is needed to investigate the link between body composition and aerobic fitness in cricket players.

Chapter 4, pg. 160 further suggests no significant differences between the aerobic fitness of pace and spin bowlers. The similarity of aerobic fitness scores between pace and spin bowlers may be linked to the intermittent nature of cricket**.** Pace bowlers engage in short bursts of running, while spin bowlers do not engage in any running before delivering the ball. The short bowling activities, including rest periods between overs, may not require sustained aerobic efforts. However, when comparing the demands of bowling activities with the demands of batting, as described above, the distinct aerobic demands of the respective roles become apparent. There may also not be distinct variations of aerobic fitness of spin and pace bowlers due to the particular structure of the aerobic fitness test and the possibility that both groups have similar

training routines and physical characteristics. To enhance the aerobic fitness of the bowlers as a group, SSSM practitioners can incorporate personalised cardiovascular conditioning plans, such as sprint or interval training, to mimic the demands of a match (Webster et al., 2022).

7.3.3 Muscle strength and power

This thesis aimed to describe female cricket players' physical strength and power profiles and provide insights into the unique physical characteristics of each player's role within a team. **Chapter 4, pg. 149-151** presents an investigation into upper and lower body muscle strength and power conducted across various player roles using hand-held dynamometers and force plate testing. The results reveal strength deficits within the entire cohort and individual player roles. All-rounders presented with superior muscle strength, body mass, BMI, and muscle mass compared to both batters and bowlers. On the other hand, batters showcased enhanced performance in isolated muscle strength and aerobic fitness.

7.3.3.1 Shoulder muscle strength

For the shoulder tests, the entire female cohort presented with a deficit in shoulder IR:ER strength ratio, irrespective of player role (**Ch. 4, Table 4-1, pg. 156-158**). Further analyses revealed that all-rounders presented with the greatest IR:ER ratio deficit compared to other player roles. The shoulder's rotator cuff muscles, crucial for joint stabilisation, play a multifaceted role in adapting to the dynamic movements needed for cricket (Portus et al., 2000). Murphy et al. (2020) found that maintaining a 1:1 shoulder IR:ER ratio is vital to reducing injury risk among female cricket players. Stuelcken et al. (2008b) found that female pace bowlers are equally prone to shoulder pain or injury compared to other overhead athletes. Tallent et al. (2020) found that injuries to all-rounders affect the outcome of matches more than single-skilled players such as bowlers and batters. All-rounders might be at an increased risk of injury compared to other player roles, emphasising the importance of clinicians aiming for a balanced 1:1 ratio of shoulder internal rotation to external rotation, particularly within this group.

Interestingly, batters and all-rounders had increased IR and ER shoulder strength in the non-dominant compared to the dominant shoulder (**Ch. 4, Table 4-1, pg. 156-158**). The shoulder strength discrepancy in batters and all-rounders implies an adaptive response to the unique batting requirements. During batting, the non-dominant arm plays a more significant role. Examining the biomechanics and anatomy reveals that the internal shoulder rotators are crucial in orchestrating the shoulder movements involved in various cricket shots (Nunes and Coetzee, 2007). The effectiveness of

batting shots like the hook, pull, cut, and sweep depends on the right arm's internal shoulder rotators (for right-handed players), which contribute to achieving optimal bat velocity at the moment of ball impact. Concentric contractions of the internal shoulder rotators of the left arm are used to perform the high backlift and to keep the bat in position. Nunes and Coetzee (2007) reported that batters use higher backlifts in attacking shots, facilitated by concentric contractions of the non-dominant internal shoulder rotators. This increased backlift, followed by eccentric contractions in the shoulder external rotators, contributes to enhanced force during ball impact, potentially demanding greater endurance from the non-dominant shoulder's internal rotator muscles in situations like one-day matches (Nunes and Coetzee, 2007). This adaptation in batters and all-rounders could explain the increased strength in the non-dominant shoulder.

Another interesting finding in **Ch. 4, Table 4-1, pg. 156-158** was that bowlers presented with the weakest IR:ER shoulder strength compared to batters and all-rounders. Relative to batters and all-rounders, the potential explanation for this diminished shoulder strength in bowlers lies in the repetitive and high-intensity bowling action. In the context of pace bowling in cricket, the acceleration phase of the arm relies on concentric contractions of the internal rotators, whereas the deceleration phase involves the external rotators (Aginsky et al., 2004). Wormgoor et al. (2010) found that faster ball release speeds of pace bowlers are associated with increased shoulder extensor and internal rotator strength. Moreover, there is a correlation between the concentric strength of the internal rotators in the bowling shoulder and years of pace bowling, indicating that the repetitive acceleration phase during bowling or throwing may contribute to gradual strength gains in these muscles over time

(Stuelcken et al., 2008b). As the sub-elite players in **Ch. 4, pg. 153** are younger than players at the elite levels it could be explained that these players will increase their muscle strength parallel with their experience and participation in cricket. However, the repetitive overuse of the shoulder in sports can lead to diminished shoulder strength over time. The reduced muscle strength of bowlers can be explained by the high shoulder injury rate seen in shoulder injuries among bowlers in **Ch. 5, Table 5-3, pg. 184**. Applied SSSM clinicians should aim to increase shoulder muscle strength to improve the physical profile of the sub-elite players as they progress to the elite level.

7.3.3.2 Knee and hip muscle strength

A consistent observation emerged in the muscle strength assessment of individual players in **Ch. 4, Table 4-1, pg. 156-158**, revealing lower strength in both dominant and non-dominant knee flexion compared to knee extension across all player roles. This novel finding is present in all player roles, irrespective of their unique roles. Cricket players rely on knee and hip extension for sprinting, jumping, and forceful leg extension needed in batting and bowling. The repetitive nature of these activities may lead to an imbalance in the quadriceps and glutes compared to the hamstring muscle group (Tallent et al., 2020). This observation raises the prospect of an adaptive response to the unique demands of batting and bowling, highlighting the need for further research in an area where limited literature exists regarding hamstring strength in cricket players.

The biomechanics of cricket actions, such as batting and bowling, often involve knee extension, potentially contributing to the observed strength pattern. A discriminating isokinetic strength variable related to muscle endurance is the total work of the left quadriceps, as identified by Tallent et al. (2020). Batters need adequate muscle endurance, especially in the quadriceps muscle. Quadriceps muscle strength is required for activities such as repeated running near maximal levels with limited rest, potentially influenced by the prolonged periods spent in a flexed knee position during the batting stance. Furthermore, positive correlations were found between the relative peak torque values of the left hamstring and the right quadriceps, indicating that lower peak torque values in these scores may result in a higher ranking order for batters (Tallent et al., 2020).

7.3.4 Functional upper and whole-body strength

The IMTP and push-up tests in **Ch. 4, Table 4-1, pg. 156-158** indicate that all-rounders outperformed both batters and bowlers. Limited evidence is available to compare our findings regarding the physical profiles of all-rounders and draw definitive conclusions on why all-rounders exhibit greater strength compared to batters and bowlers. It can be suggested that all-rounders performed better in the IMTP and push-up test as these players may be engaged in a more holistic training program. This includes targeting general muscle groups for bowling, batting, and performing both skills during training. In contrast, batters and bowlers, focusing on their unique skill sets, may train specific muscle groups relevant to their respective roles (Feros et al., 2020; Singh et al., 2023). Given the differences between batting and bowling as skill sets, all-rounders who engage in more versatile physical preparation and skills training may experience

increased physical demands. The physical demands could indirectly contribute to all-rounders presenting with increased MM% and muscle strength observed in **Ch. 4, Table 4-1, pg. 156-158**. Greater IMTP results have been linked with higher ball speed for pace bowlers (Kiely et al., 2021). Therefore, SSSM practitioners should target improving overall body strength in pace bowlers to enhance their performance in the IMTP test."

7.3.5 Functional lower body strength

Several differences are evident between each player's role in the lower limb muscle strength and power testing using the CMJ, SLJ and HT (**Ch. 4, Table 4-1, pg. 156-158**). All-rounders presented with the highest power in the CMJ and HT compared to other player roles. Consistent with the significant IMTP and push-up test findings, all-rounders presented with increased strength and power which is likely due to the multifaceted nature of their roles and the increased physical demands of performing both the batting and bowling skills, as explained in the previous section.

No significant differences were observed in SLJ between dominant and non-dominant sides for the entire sub-elite female cricket cohort. However, batters displayed higher power in non-dominant SLJ than other player roles. The increased non-dominant SLJ results could result from an adaptation of the muscle endurance of the left quadriceps muscle during batting, as identified by Tallent et al. (2020). Batters need effective muscle endurance, especially in the quadriceps muscles when involved in repeated sub-maximal running with limited resting periods, potentially influenced by the

prolonged periods spent in a flexed knee position during the batting stance (Tallent et al., 2020).

Bowlers demonstrated the highest jump height in CMJ and the dominant SLJ (**Ch. 4, Table 4-1, pg. 156-158**). Jump height is generally used to assess lower-body power (Cronin and Hansen, 2005) and could be an adaptation to the nature of bowling as pace bowling is an explosive intermittent activity that requires adequate acceleration speed in conjunction with lower-body power and power endurance. Pyne et al. (2006) observed variations in the physical predictors of peak bowling speed for junior and senior pace bowlers. These predictors, including static jump, bench throw, CMJ, and body mass, explain 74% of the variance in peak bowling speed for junior pace bowlers (Pyne et al., 2006). While bowlers generally exhibit lower leg strength and power than batters and all-rounders, they also display greater jump heights in the CMJ and non-dominant SLJ. These adaptations could be linked to the specific requirements of their position, emphasising the need for bowlers to excel with their non-dominant leg before back foot contact, as explained in **Ch. 6, pg. 218-220**. The significance of this adaptation is supported by the findings in **Ch. 4, Table 4-1, pg. 156-158**), where bowlers consistently exhibited higher power and jump height in the non-dominant SLJ, reflecting the adaptation to their unique bowling biomechanics.

Investigations into spin and pace bowlers demonstrated significant differences in muscle strength and power (**Ch. 6, pg. 218-220)**. The functional muscle strength tests indicated variations for SLJ and CMJ between pace and spin bowlers. Pace bowlers presented with higher peak power, RFD and jump height in the jump tests. The RFD

and muscle-tendon unit stiffness can explain this adaptation of pace bowlers in various phases and the combination of physical capacity and technique to enhance ball release speeds (Aagaard et al., 2002; Felton et al., 2019). Consequently, evaluating and improving pace-bowling performance requires both physical and technical factors. Spin bowlers, by comparison, tend to perform at much lower physical and physiological intensities than pace bowlers, most likely due to the lower bowling speeds and differences in bowling biomechanics (Vickery et al., 2018a). Furthermore, Webster et al. (2022) found major discrepancies between training and the game for spin bowlers, which were recorded mainly in the high-intensity movement categories (running and striding) compared to pace bowlers.

Pace bowlers demonstrate higher performance levels, likely due to the specific biomechanical demands associated with their bowling action (Felton et al., 2019; Letter et al., 2022a; Letter et al., 2022b). The explosive nature of pace bowlers requires rapid force and power from their lower limbs during the run-up and upper body acceleration during the bowling action (Felton et al., 2019). Pace bowlers have a unique biomechanical advantage that allows them to generate explosive power for executing swift movements in pace bowling. This characteristic is not typically seen in the biomechanics of spin bowling. The comparatively lower physical and physiological intensities in spin bowlers, as opposed to pace bowlers, could account for the disparities in strength and power observed between the two bowling groups.

7.3.6 Summary of the physical differences between each player role

All-rounders performed superior in muscle strength testing and had the highest body mass, BMI, and MM%. All-rounders had the highest isolated muscle strength for shoulder IR and ER. All-rounders also presented with the highest muscle strength for knee flexion, extension, and hip extension compared to bowlers and batters. The superior strength characteristics of all-rounders are likely linked to the adaptations to meet the physical demands of all-round play, including participation in batting and bowling skill sessions and holistic strength and conditioning sessions. The physical profile of allrounders described in this thesis is likely the outlined ideal phenotype for a typical all-rounder in women's cricket.

Batters had increased muscle strength for all shoulder tests, CMJ, SLJ, HT and IMTP than bowlers but less than all-rounders. Batters presented with significant differences in the non-dominant leg compared to the dominant leg in the SLJ. Batters presented with the best performance in the aerobic fitness test compared to bowlers and all-rounders. Batters performed the best in the 2km TT, which could be explained by the short bursts of running between the wickets over a long period, as explained in **Ch. 7, pg. 232**. Incorporating short-distance, high-intensity running over a more extended period could enhance aerobic fitness; integrating drills such as shuttle runs, interval training, or simulated match situations may contribute to this improvement.

Bowlers performed lower in isolated upper- and lower-body and functional muscle strength and aerobic tests than all-rounders and batters. However, bowlers showed higher jump heights in CMJ and SLJ. This increased jump height may be an adaptive response to the biomechanics of the bowling action, as explained in the previous

sections. This difference in training emphasis does not necessarily indicate a disadvantage for bowlers. Instead, it highlights the tailored approaches players take to optimise performance in their specific roles on the field. SSSM practitioners should tailor strength and conditioning programs for bowlers, considering their lower performance in isolated upper- and lower-body tests, but account for biomechanical adaptations from higher jump heights to optimise the performance of bowlers.

7.4 Injury profiles in sub-elite female cricket players

Injury incidence and prevalence of sub-elite female cricket players were investigated in **Ch. 5, pg. 173** addressed an important research aim for this thesis as listed in **Ch. 1, pg. 4**. Injury surveillance studies are the first step to guide injury prevention programs needed in the female cricket population. The injury incidence for sub-elite women's cricket (including time-loss) was lower than at elite levels. Pace bowlers had the highest injury incidence. Fielding was the activity that caused the most injuries. The wrist, hand and finger regions had the highest incidence and caused the most missed time due to injury.

The overall injury incidence rate for sub-elite female cricket players in **Ch. 5, pg. 181** was 85.23 per 1000 player match days. The incidence of match time-loss injuries in sub-elite players in this chapter was higher (15.91 per 1000 players per year) when compared with international pathway cricket in the UK (7.0 per 1000 player match days) (Goggins et al., 2020b). There were also lower rates of time-loss injuries among sub-elite women's cricket **Ch. 5, pg. 181** compared to other injury rates at the pathway and elite levels. Various factors could influence this difference. Firstly, specific studies,

like the UK international pathway cricket, mention illness and injury, potentially explaining the higher rates (Goggins et al., 2020b). Another possible factor may be linked to the lower level of professionalism at the sub-elite level compared to the more elite levels.

Further, the teams included in **Ch. 5, pg. 181** only had five contracted players, compared to the pathway level, where players will have part-time contracts (Goggins et al., 2020c) and the elite level, where all players have full-time contracts (Orchard et al., 2023b). Players lacking professional contracts and financial backing engage in cricket training and matches alongside their work and personal commitments, constraining their capacity to dedicate themselves fully to skill development and performance. The players in this chapter were also younger than participants in other women's cricket studies (Orchard et al., 2023b; Perera et al., 2019c; Warren et al., 2019). Players at the sub-elite levels have limited experience and exposure to skills development compared to elite cricket players. Players at lower levels may have less opportunity for skill development, match exposure, and physical capacity compared to those at higher levels of the sport (Kelly et al., 2019).

The injuries reported in **Ch. 5, Table 5-2, pg. 182** occurred more frequently in 20 over matches compared to 50 over matches. The intensity of cricket played in 20 overs is higher compared to longer game formats. It might explain the higher rate of injuries seen in 20 over cricket, even though there are fewer playing hours compared to 50 overs. To prepare the player for the increased demands of T20 cricket, SSSM

practitioners can employ focused training programs that emphasise explosive power, agility, and refined technical skills.

Although the injury rates were high in matches, more injuries were sustained during training than in matches (**Ch. 5, Suppl. Table 5-1, pg. 196**). The technical demands of traditional net cricket training surpass those of a typical match for each playing position, especially for bowlers (Vickery et al., 2018b). Training also exposes players to direct contact and non-contact risks. Contact injuries could be more frequent because players are exposed to different dangers during training. The increased contact risk, for example, can be multiple balls in play during training compared to matches as more than one stimulated play is happening during net sessions or more than one ball during fielding sessions.

Fielding was the activity that caused the most injuries (**Ch. 5, Suppl. Table 5-2, pg. 196**). The body regions most injured were the hand, wrist, and fingers, which resulted from direct contact with the ball or the ground. All players are expected to field and are at risk of sustaining both direct and indirect contact injuries. Skills development in younger age groups could reduce injury risks (Perera et al., 2019b; Bristi, 2015; Grimmer et al., 2000). Skills development and using PPE such as gloves will also reduce the high incidence of hand injuries in cricket players (Brooks et al., 2020). The use of cricket gloves designed with reinforced padding during fielding and catching training, as well as technique training, such as improved pre-catching hand and body positioning, ground diving techniques and ball gripping technique, could enhance the technical skills of female cricket players in catching and fielding to reduce the risk of

injury. Hand and eye coordination can enhance a player's ability to track the ball and make precise movements during batting or fielding. The heightened coordination contributes to overall cricket performance. It can reduce the risk of hand injuries by enabling players to react more effectively to the ball, positioning their hands optimally for safe catches or shots.

Pace bowlers in **Ch. 5, Table 5-3, pg. 184** experienced the highest injury incidence and muscle-related injuries and missed the most time due to injury compared to spin bowlers and batters. Female pace bowlers may face increased injury rates due to kinetic and kinematic risk factors. In elite women's cricket in Australia (Perera et al., 2019c) and the UK (Warren et al., 2019), pace bowlers experienced the highest number of injuries. Research indicates that female pace bowlers face higher kinematic and kinetic injury risks in comparison to spin bowlers and other player roles (Stuelcken et al., 2010b; Stuelcken et al., 2010a; Stuelcken and Sinclair, 2009). The shoulder's distraction force may also play a role in causing shoulder injuries in female pace bowlers (Stuelcken et al., 2010a). Tailored strength and conditioning programs can effectively target muscle imbalances and improve neuromuscular control (Cowan, 2006). SSSM practitioners should effectively address players' evolving needs and physical progress through regular monitoring to adapt physical preparation programs. A suggestion is that stakeholders in sub-elite women's cricket should prioritise the employment of SSSM practitioners at the sub-elite levels to improve these players' physical preparation and medical management.

7.5 Description of the female pace bowling profile

Pace bowling is a critical success factor of a cricket team, as pace bowlers have wicket-taking abilities due to the speed of their deliveries. The fast-bowling action requires optimal biomechanics to increase ball release speed and reduce the time that the batter has to face the delivery (Wormgoor et al., 2010; Portus et al., 2004; Glazier et al., 2000). Female fast bowling biomechanics have previously been described as having slower run-up speeds compared to males, resulting in less whole-body momentum. The loss of whole-body momentum is then compensated by using rotation in the thorax and pelvis to generate angular momentum (Felton et al., 2019).

The female pace bowling biomechanics is described in **Ch. 6, pg. 213-223**. Findings suggest that female pace bowlers spend longer in the phase lengths through the delivery stride, specifically from BFC to FFC. Females present with increased pelvis and trunk rotation from BFC to FFC and BR to one step after BR and increased total shoulder counter-rotation. The extended time of the phase length through the delivery stride enables the female bowlers to use muscles working in the transverse plane to generate extra rotational momentum to increase ball release speed. The biomechanical differences observed between female and male pace bowlers, including an extended transition from back foot contact to front foot contact, reduced hip flexion, and slower ball release speeds, indicate sex-specific differences in bowling biomechanics. Further differences include shoulder counter-rotation, trunk side flexion techniques, and specific pelvic and trunk rotation patterns among female pace bowlers.

A noteworthy finding in **Ch. 6, pg. 215-222** was the disparity in trunk side flexion between males and females. Females presented with trunk side flexion to the left compared to a neutral (upright) trunk position of the males before-BFC. Females then transition to side-flexion to the right, whereas males maintain a neutral (upright) trunk at BFC. Males and females present with increased trunk side flexion towards the left at FFC.

Interestingly, the magnitude of left trunk side flexion from BFC to FFC was similar for both sexes. However, males exhibited an augmented total magnitude of right-side trunk side flexion at FFC due to their neutral (upright) trunk position at BFC, in contrast to females who initially presented with left-side trunk flexion at BFC. This technique could be beneficial for the females as previous research indicated that female fast bowlers had proportionally longer trunk lengths than male pace bowlers (Stuelcken et al., 2007) and could be an anthropometrical and biomechanical advantage for the females to use right to left trunk side flexion to generate momentum during the delivery stride.

The physical profile of a female pace bowler is described in **Ch. 4, pg. 153**. Bowlers presented with the lowest body mass, RMR and MM% and the highest BF% compared to batters and all-rounders (**Ch. 4, pg. 156**). The observed body compositions for female bowlers in this study may indicate a preference for endurance training methods over explosive power training, typically favoured for batting skills. Pace bowlers presented with higher peak power, RFD and jump height in the jump tests. The RFD and muscle-tendon unit stiffness can explain this adaptation of pace bowlers in various

phases and the combination of physical capacity and technique to enhance ball release speeds (Aagaard et al., 2002; Felton et al., 2019). The explosive nature of pace bowlers requires rapid force and power from their lower limbs during the run-up and upper body acceleration during the bowling action (Felton et al., 2019). Pace bowlers have a physical profile that allows them to generate explosive power for executing swift movements during pace bowling.

The scoping review in **Ch. 3, pg. 73-82** highlight that the physical preparation of pace bowlers is vital as muscle strength influences ball release speed (Letter et al., 2022a). Upper and lower body strength affects ball release speed in female pace bowlers (Letter et al., 2022a). The physical qualities of pace bowlers improve with age due to training effects that gradually enhance ball release speed (Letter et al., 2022b). Female pace bowlers use thoracic and pelvis rotator muscles to increase ball release speed (Felton et al., 2019). Applied SSSM should improve lower body strength, anaerobic capacities, and upper body pulling strength as physical preparation guidelines for pace bowlers (Letter et al., 2022a). Bowlers tend to have lower individual muscle group strength and functional muscle strength compared to other player roles. Applied SSSM should have individual approaches to enhance their muscle mass and strength, including collaborating with a dietitian and strength and conditioning coach.

The injury profile of female pace bowlers is described in **Ch. 5, Table 5-3, pg. 184**. Pace bowlers had the highest injury incidence and muscle-related injuries and missed the most time due to injury compared to spin bowlers and batters. Female pace bowlers may face increased injury rates due to kinetic and kinematic risk factors. In elite

women's cricket in Australia (Perera et al., 2019c) and the UK (Warren et al., 2019), pace bowlers experienced the highest number of injuries. The scoping review in **Ch. 3, pg. 42**, highlights that pace bowlers are more frequently injured than other player roles (Bipasha et al., 2018). Pace bowlers are at a greater risk of injury than players in other positions due to their complex and physically demanding bowling action (Portus et al., 2004). Pace bowlers are prone to overuse injuries and biomechanical strains due to their bowling technique (Dennis et al., 2005). Lower back injury rates in female pace bowlers are reduced compared to males (Jacobs et al., 2022). Murphy et al. (2020) found that a shoulder IR:ER strength ratio >1.00 is the strongest risk factor for developing shoulder injury. Stuelcken et al. (2010a) found that shoulder distraction force in female pace bowlers is likely a contributor to shoulder pain due to rotor cuff injuries. The shoulder strength ratio deficits and distraction force combined with excessive shoulder rotation in the biomechanical action to increase ball release speed could increase the risk of injury for female pace bowlers. Additional research is needed to examine the trade-off between the shoulder counter-rotation that enhances bowling performance and the increased risk of shoulder injuries associated with this technique. In terms of practical implication, it is recommended that SSSM clinicians prioritise the strengthening of shoulder.

The scoping review (**Ch. 3, pg. 42)** further highlighted that applied SSSM practitioners should be aware of bone density deficits in female pace bowlers (Alway et al., 2023; Jones et al., 2018b) and LSBI (Saw et al., 2023). Applied SSSM practitioners should diligently identify early clinical symptoms of bone-related injuries and refer female pace bowlers to medical doctors for confirmed diagnoses through magnetic resonance imaging (MRI) (Saw et al., 2023). To reduce the risk of lumbar spine injuries, SSSM

practitioners can monitor bowling biomechanics, load management, and back stability programs (Perera et al., 2019a-a). Implementing early conservative treatment for bone-related injuries in female cricket players can help reduce the recurrence and severity of the condition.

This thesis explored the anthropometrics and biomechanics of female pace bowlers, highlighting the importance of tailored coaching strategies and applied SSSM interventions for female pace bowlers. The unique physiological characteristics of female cricket players are evident through significant differences in anthropometric measurements compared to male bowlers. These variations include arm span, hip height, overall height, and shoulder height. Applied SSSM practitioners should implement strength and conditioning programs to accommodate the distinct anthropometric variations and physiological characteristics observed in female cricket players. Prioritising individualised training strategies is crucial for optimising performance (Lascu et al., 2022b) and reducing the risk of injury (Forrest et al., 2018).

Further, the findings from this study highlight the importance of considering the unique biomechanical strategies in coaching and training programs. Applied SSSM practitioners and coaches should understand the trade-offs between performance enhancements and injury risks associated with specific biomechanical patterns in bowlers (Phillips et al., 2012). Future research should investigate larger cohorts to explore the relationship between physical profiles and biomechanics of female pace bowlers.

7.6 Strengths of this thesis

The scoping review in **Ch. 3, pg. 42** addressed significant gaps in SSSM for female cricket players and increased the current body of evidence for female cricket players. The PRISMA Scoping Review Protocol and JBI scoping review methodology guided the scoping review. Another strength is that several peer-reviewed databases, two trial registers, and four grey literature databases were searched to locate studies. The scoping review included a total of 158 studies to direct current SSSM practices as well as guide future research priority areas.

The physical profiles and preparation study in **Ch. 4, pg. 142** used computed objective measurements such as dynamometry and force plates for objective measurements to present accurate results. The study establishes baseline values for the physical profiles of sub-elite female cricket players by using a comprehensive performance test battery that includes assessments of body composition, strength, and aerobic fitness, ensuring a thorough evaluation of the physical attributes relevant to cricket performance. By focusing on a specific cohort (i.e. sub-elite female cricket players), the study offers targeted insights that can inform the development of more tailored training programs and injury prevention strategies for this population.

In **Ch. 5, pg. 173**, three data sources for the injury study were used to verify the data collection and reporting for the injury surveillance study. All self-reported injuries were confirmed with medical team members. Another strength of this study is that all injuries sustained during matches and training and time missed were reported for an objective overview of all injuries sustained in sub-elite women's cricket.

For the bowling biomechanics study in **Ch. 6, pg. 201**, three-dimensional software, the gold standard in bowling biomechanical analyses, was used for data capturing. Another strength of this study is the use of IMU, as the players could be exposed to an outdoor pitch and environment, which improved the ecological validity as it was closer to match and training circumstances than indoor testing on artificial surfaces. Also, reporting the before-BFC and one step after BR is a strength of this study, as the fast-bowling action should be assessed holistically, not just the transition from BFC to BR. Future studies should include before-BFC as part of their bowling analyses. This segment predicts the setup of kinematics at the BFC, and the transition from before-BFC to BFC is an essential technique coaches reinforce in their bowlers during coaching sessions. Finally, expert data analysts were included for advanced data analysis for the three-dimensional bowling biomechanics study and the physical profiles study to provide high-quality statistical analysis support.

7.7 Limitations of this thesis

This study offers important insights into the physical profiles of sub-elite women's cricket players, but some limitations must be acknowledged. The study samples in **Ch. 4, pg. 142** and **Ch. 5, pg. 173** were limited to a specific geographical area and a small cohort, potentially impacting the generalisability of the findings to other sub-elite female cricket populations. The study's cross-sectional design hinders the establishment of cause-effect relationships between musculoskeletal profiles and performance outcomes. The IMTP results were not normalised to body mass and may influence the results in **Ch. 4, pg. 142**. We suggest that future researchers investigate shoulder

musculoskeletal testing in end ranges to explore the effects of eccentric muscle strength at longer muscle lengths. Also, future research should explore alternative physical strength assessments, such as an open kinetic chain test without end-range deceleration, like a medicine ball throw, to expand the scope of research for female cricket players. A final limitation of this study is the small population of elite female pace bowlers in **Ch. 6, pg. 201**. However, considering the small population of elite female pace bowlers in any cricket nation, it is still a big group. Future research should investigate a larger cohort of elite female pace bowlers, the relationship between musculoskeletal, anthropometrics and bowling biomechanics, and how these factors could influence ball release speed and injury risk.

CHAPTER 8. CONCLUSION

8.1 Conclusion of this thesis

The overall theme of this thesis was to identify and describe the unique biomechanical bowling pattern, anthropometric and physical characteristics and injury profiles of female cricket players. This thesis aimed to undertake a comprehensive research programme to map the available evidence and identify priority research areas for female cricket players.

This thesis presents a scoping review of the current evidence available for SSSM for female cricket players. The findings from the scoping review summarised current knowledge and serve as a stepping stone in identifying SSSM topics for future research. This thesis also investigated the physical profiles of female cricket players and provided baseline values of all-rounders, batters, pace and spin bowlers in women's cricket to assist applied SSSM for the physical preparation of female cricket players. Investigations into the physical profiles of female cricket players suggest that all-rounders exhibit greater muscle strength, power, body mass, and muscle mass than bowlers. The study further highlights the reduced dominant and non-dominant knee flexion strength in batters, bowlers and all-rounders.

Moreover, bowlers displayed lower muscle strength and body and muscle mass yet demonstrated higher jump heights when compared to batters and all-rounders. Batters had superior aerobic fitness relative to other player roles. All-rounders had the greatest

IR:ER shoulder ratio deficit and might be at risk of a shoulder injury. Considering the unique musculoskeletal profiles of each player's role reported in this thesis, SSSM practitioners should have individualised approaches for the physical preparation for each player role.

This thesis addressed a vital research gap, providing findings for the injury profiles at sub-elite level in women's cricket. To the author's knowledge, this is the first study to provide a detailed profile of the incidence rate and prevalence of injuries among the sub-elite female cricket population. This study provides evidence-based injury profiles in sub-elite women's cricket that can be used as the first step to guide injury prevention programs at the sub-elite level. It is suggested that injury prevention strategies should be focused on ball-catching techniques, hand-eye coordination and taking the ground during fielding to minimise the high incidence of direct contact injuries seen in fielding among this cohort. It is also suggested that physiotherapists should be appointed at the sub-elite level to manage the high incidence of direct contact injuries in matches in training.

This thesis also contributed to the overall body of SSSM evidence for female pace bowlers. Findings suggest that female pace bowlers have unique anthropometry and bowling biomechanics compared to males. Female pace bowlers spend more time transitioning through the delivery stride, present with a more front-on approach when arriving at the delivery stride and present with greater pelvis and trunk rotation displacement during the delivery stride compared to males. A novel finding of this study is that females use a different trunk side flexion strategy compared to males. Bowling

coaches and applied SSSM can use these findings when coaching female pace bowlers.

8.2 Practical implications

The scoping review in **Ch. 3, pg. 42** maps all applied SSSM research for female cricket players. The review includes practical implications for clinicians working with female cricket players and maps the literature under the following SSSM themes: injury, performance, psychology, health, physical characteristics, match characteristics, fatigue and recovery and nutrition and hydration. The findings from **Ch. 4, pg. 142** suggest physical differences between batters, bowlers and all-rounders in women's cricket. The findings for each player role will enable applied SSSM practitioners to guide physical preparation programs. All player roles present with reduced hamstring muscle strength in the non-dominant leg. Current physical preparation programs should aim to increase hamstring strength and reduce the deficit between the dominant and non-dominant legs. Batters present with the lowest hamstring muscle strength compared to bowlers and all-rounders. All-rounders presented with a dominant shoulder IR:ER ratio deficit, predisposing them to shoulder injury. Practitioners should aim to increase the IR:ER ratio to 1:1 to reduce injury risk for all player roles, specifically for all-rounders.

Chapter 5, pg. 173 identified injury incidence and prevalence among female cricket players. Injury prevention strategies are recommended to be implemented to reduce direct contact injuries, specifically during fielding (e.g., catching the ball without injury and taking the ground during fielding to minimise the injury risk) and non-contact

injuries in pace bowlers. It is also recommended that physiotherapists and other medical staff should be appointed at the sub-elite level to manage the high incidence of direct contact injuries in matches in training. Technical factors and skills such as hand-eye coordination could contribute to the high incidence of hand, wrist, and finger injuries seen during fielding, and implementing injury prevention strategies to address these factors might reduce the risk of injury. Applied practitioners should attend to the physical profile of bowlers (pace and spin) as they present with reduced muscle strength compared to other player roles. Also, the body composition of the pace and spin bowlers in Paper 2 reveals a high body fat percentage and reduced muscle mass compared to batters and all-rounders. Applied SSSM staff should attend to bowlers to increase muscle mass and strength, including the collaboration of the dietitian and strength and conditioning coach. **Chapter 6, pg. 202** highlights the unique biomechanical action of female pace bowlers and guides SSSM practitioners and coaches in having a unique approach when coaching female pace bowlers.

8.3 Future research directions for female cricket players

A scoping review (**Ch. 3, pg. 42**) was conducted as part of this thesis to identify current literature gaps and shape future research directions for female cricket players. **Chapter 3, Table 3-3, pg. 92**, presents the SSSM themes identified for future research in women's cricket. These include female health, long-term health, well-being, injury prevention, physical preparation, psychological support, nutrition and hydration to enhance female cricket players' understanding and overall management. Future research should explore the physical profiles of female cricket players across various levels of play and geographical locations to compare baseline values among different

populations, enhancing the generalisability of the results and supporting players' physical preparation. Moreover, investigating the risk factors associated with injuries highlighted in **Ch. 5, pg. 173**, such as those caused by pace bowlers, hand and wrist injuries, shoulder injuries, and lower limb injuries among female cricket players, is crucial. Additionally, exploring biomechanical factors linked to both injury and performance for female cricket players, alongside ongoing research into the optimal pace bowling technique for female pace bowlers, is recommended for a comprehensive understanding and improvement of female cricket players.

Additional information relevant to this thesis

A plagiarism report is included in **Appendix L.**

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APPENDICES

APPENDIX A - PHYSICAL PROFILES OF ALL-ROUNDERS, BATTERS, AND BOWLERS IN SUB-ELITE WOMEN'S CRICKET

Original Research

Journal of Strength and Conditioning Research™

Physical Profiles of All-Rounders, Batters, and Bowlers in Sub-Elite Women's Cricket

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Abstract

Jacobs, J, Olivier, B, Brandt, C, and Jafta, G. Physical profiles of all-rounders, batters, and bowlers in sub-elite women's cricket. *J Strength Cond Res* 38(6): 1095–1102, 2024—The unique physical profile of each player's role in sub-elite women's cricket is vital for optimizing performance as these players progress to the elite levels. This quantitative, cross-sectional study investigates the physical profiles of sub-elite women's cricket players as a group and compares these profiles across different player roles. Sub-elite female cricket players in the South African domestic women's cricket league were included in this study. A battery of physical assessments were conducted at the start of the 2022/23 season. The physical assessments included body composition, individual muscle strength testing using dynamometry, 2-km time trial (TT), countermovement jump (CMJ), single-leg jump (SLJ), isometric mid-thigh pull, push-up, and hop test on force plates. A total of 44 female players (20.86 ± 1.6 years) were included in the study. Differences were found in muscle mass ($p = 0.004$) and peak power ($p = 0.040$) for all-rounders and bowlers. Player roles presented with different dominant ($p = 0.006$) and non-dominant ($p = 0.066$) knee flexion strength. The bowlers' body composition and physical strength profile are compromised compared with batters and all-rounders. There were several physical strength and power differences between pace and spin bowlers in CMJ and SLJ tests for jump height ($p = 0.009$) and peak power ($p = 0.006$). Batters performed the best in the 2-km TT. Body composition and musculoskeletal profiles for each player role can be baseline markers in sub-elite women's cricket. Stakeholders can use this information to guide physical preparation for players advancing to elite levels.

Key Words: physical preparation, female cricket, team sport, musculoskeletal screening, muscle strength, preseason

Introduction

Women's cricket is drastically rising in participation and professionalism across the globe. The interest in women's cricket has also lured the sports science and medicine community in recent years (7,11). Sports science and medicine researchers in cricket investigate musculoskeletal health with physical preparation, performance enhancement, and injury prevention outcomes. The musculoskeletal system plays a crucial role in cricket, particularly in batting, bowling, and fielding. It enables athletes to make rapid changes in direction, accelerate, and maintain power and stability during gameplay. There is evidence to suggest that several physical factors, including body composition and muscle strength, have a significant impact on cricket performance (2,33). Therefore, prioritizing the physical preparation of cricket players is crucial to achieve optimal performance.

It is essential to understand the physical profile of players to develop physical preparation guidelines in cricket. Physical preparation guidelines are widely researched in men's cricket (32), including physical profiling for individual player roles, such as bowlers and batters (8). The same is not evident for women's cricket because current research supporting physical preparation for female cricket players focuses on female players as a group (18) or explores the profiles of elite pace bowlers (11,12,26). Letter et al. (11) found that faster female pace bowlers possess superior physical characteristics, such as maximal upper-body muscle strength, compared with slower pace bowlers. However, there was no difference in countermovement jump (CMJ) height among the faster and slower female pace bowlers (11). Letter et al. (12) found changes in physical profiles between different age groups but no changes for seasonal assessments. Letter et al. (11) suggested that improving lower-body strength, anaerobic capacities, and upper-body pulling strength may enhance performance in female pace bowlers. Murphy et al. (18) found a dominant arm internal rotation:external rotation strength deficit ratio in female cricket players and linked this with a 1.79 times increased risk of shoulder injury.

Differences exist between the physical profiles and demands among various player roles (8,32). Identifying individual shortcomings and tailoring approaches to the subroles in cricket is crucial, considering each player's diverse demands and physical capacities (32). The lack of existing research on the physical

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belts (indirect isometric resistance) for standardized testing procedures. The lower-leg muscle strength test was performed using the direct application of the dynamometry with the player in a prone position (9). To standardize the measurements, the same testing individual who conducted the dynamometry tests was used to test all the players in all of the teams. The trial was immediately terminated if the tester detected compensatory movements, such as moving the humerus into shoulder abduction when external rotation was required or excessive lumbar extension during hip extension testing. The player was then requested to perform the test again without compensatory movements to standardize testing. A 30-second rest period (11,12) was allowed between each trial, including any incorrect trials. Each muscle group was tested 3 times, with the average value of the 3 tests recorded for data analysis.

Functional Muscle Strength Tests. All functional muscle strength tests were done according to VALD ForceDecks protocols (see Table S1, Supplemental Digital Content 1, http://links.lww.com/JSCR/A463). All tests conducted on the force plates were captured, cleaned, and analyzed using VALD ForceDecks software (VALD, ForceDecks, Brisbane, Australia). Jump testing using the force plates involved subjects starting at a normal mean force (N). The CMJ test, single-leg jump (SLJ) test, and hop test (HT) were used to determine lower-body muscle strength and power. The isometric mid-thigh pull (IMTP) and a velocity push-up were used to assess upper-body muscle strength and power. Variables, such as jump height, peak force, peak power, velocity at takeoff, and power, are all reliable coefficients of variation (CV < 10%) (23). Interrater coefficients of variation are less than 0.6% for the SLJ, indicating good reliability for these tests (16). Studies have indicated good interrater and intrarater reliability for the IMTP test (14). The instructions for the jump test were to "jump as high as you can" and for the strength test to "push as hard as you can into the force plates." For all the jump tests, no arm swing was allowed. Each player had 1 testing trial for each test, with the tester correcting the player as needed. The testing trial was not recorded. After that, each subject's body mass was recorded to normalize the data per body mass. Players were asked to perform three maximum trials for each test (CMJ, SLJ, HT, and IMTP). For the CMJ, SLJ and IMTP subjects were asked to do a single repetition and were allowed 30 seconds of recovery time before another repetition was done (11,12). Players were allowed five minutes of rest before advancing to a new testing procedure. The average value of the three tests was recorded. For the HT, players had 1 trial of continuous jumps (30). Players were requested to "jump as high as possible for 10 consecutive jumps." The average peak force of five tests from a single testing trial was used for data analysis.

Aerobic Fitness Test. On a separate day from the body composition and strength testing, the players' aerobic capacity was determined by completing a 2-km TT. Time trials have good retest reliability (10). The players were instructed to run a 2-km TT wearing their trainers around the boundary line of a cricket field. The 2-km TT distance was measured beforehand for standardization of the test. Only 1 trial of the 2-km TT was captured for analysis.

Statistical Analysis

All the data from the force decks, muscle strength tests, aerobic test, and body compositions were exported to Microsoft Excel (Microsoft 365, Microsoft Corporation, WA). For accurate analysis of left-handers and right-handers, we used the terms "dominant" and "non-dominant" when referring to either the left or right side. Data were displayed as overall means and standard deviations for all variables. Further analyses investigated discrepancies between subgroups, namely, batters, bowlers (pace and spin), and all-rounders. Should the test have dominant and non-dominant variables, additional analyses were done to investigate whether the measurements differed for all subjects. Analyses were done using the *t*-test, Kolmogorov-Smirnov (KS), or Kruskal-Wallis test. In all statistical tests conducted, the Shapiro-Wilk test was used for normality. We then compared the results of the batters, bowlers, and all-rounders using analysis of variance (ANOVA) or the KS test, depending on adherence to ANOVA assumptions (normality, equal variance, and independence). This was followed by testing for differences between pace and spin bowlers using the *t*-test or KS test, depending on the data distribution. The effect sizes were calculated using Cohen's *d*, omega squared, and eta squared. All statistical analyses were performed using R (version 4.2.2) and R Studio (version 2023.3.0.386) software (29).

Results

Player Characteristics

A total of 44 female subjects with a mean age of 20.86 ± 1.60 years participated in the study. Players ($n = 44$) were divided into subgroups for further analysis: batters ($n = 15$), bowlers ($n = 15$), and all-rounders ($n = 14$). The bowlers were subdivided into pace ($n = 19$) and spin bowlers ($n = 9$). There was 1 left-handed bowler and 2 left-handed batters.

Body Composition

The body composition for each player role is indicated in Table 1. The total means for body composition can be seen in Supplemental Digital Content 1 (see Table S2, http://links.lww.com/JSCR/A463). All-rounders had the highest overall body mass, BMI, and MM% compared with other player roles. Bowlers had the lowest body mass and MM% compared with the other body roles. There was lower MM% ($p = 0.019$, effect size (ES) = 0.18) and RMR ($p = 0.004$, ES = 0.23) for bowlers compared with all-rounders. Body composition analysis between pace and spin bowlers showed no major differences.

Isolated Muscle Strength Tests

Isolated muscle strength of the upper and lower limbs of all player roles can be seen in Table 1. All-rounders had increased strength of dominant and non-dominant internal rotators (IR) and shoulder ER compared with batters and bowlers. Batters had increased rotational shoulder dominant and non-dominant strength compared with bowlers. Bowlers had the lowest overall muscle strength for both upper and lower muscle strength compared with batters and all-rounders. There were differences in shoulder IR for spin bowlers ($p = 0.013$) and knee flexion for both pace ($p = 0.001$) and spin bowlers ($p = 0.014$). All-rounders had increased knee flexion, knee extension, hip extension, and muscle strength compared with batters and bowlers. Batters had the highest knee extension strength compared with all-rounders and batters. There were differences when implementing the KS test in dominant knee flexion for all the player roles.

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Table 1

Group means, *SD*, and *p* value for body composition and musculoskeletal testing for sub-elite female cricket players per player role.*†

Variables	All-rounder	Batter	Bowler	*p*	Effect sizes	Pace bowler	Spin bowler	*p*	Effect sizes
Body composition									
Body mass (kg)	70.14 ± 11.91	65.9 ± 9.0	62.09 ± 9.03	0.113[a]	0.10[z]	65.03 ± 10.37	66.75 ± 12.67	0.716	0.15[z]
BMI (kg·m^{-2})	24.27 ± 3.75	23.17 ± 3.2	23.17 ± 3.18	0.596[a]	0.02[z]	23.04 ± 3.03	24.27 ± 3.6	0.370	0.37[z]
Body fat (%)	31.05 ± 7.27	31.07 ± 7.83	34.23 ± 5.59	0.365[a]	0.05[z]	31.54 ± 5.83	34.24 ± 7.94	0.358	0.39[z]
Muscle mass (%)	30.51 ± 3.32	29.5 ± 3.7	26.98 ± 3.08	0.019[a]	0.16[z]	29.12 ± 3.37	28.05 ± 4.31	0.507	0.26[z]
RMR (kcal)	1,477.87 ± 111.03	1,403.79 ± 104.46	1,336.2 ± 114.01	0.004[a]	0.23[z]	1,403.63 ± 117.54	1,400 ± 162.45	0.951	0.03[z]
Isolated muscle strength tests									
Shoulder IR (D) (N)	84.07 ± 33.62	71.79 ± 37.73	69.87 ± 24.19	0.465[b]	0.01[y]	74.05 ± 30.03	76.56 ± 25.61	0.814[c]	0.09[y]
Shoulder IR (ND) (N)	87.64 ± 31.39	74.86 ± 41.98	70.8 ± 20.31	0.163[b]	0.04[y]	74.05 ± 26.41	86.78 ± 28.7	0.342[c]	0.46[y]
Shoulder ER (D) (N)	69.21 ± 22.04	68.86 ± 32.27	63.73 ± 14.77	0.702[b]	0.03[y]	62.26 ± 15.31	74.00 ± 23.52	0.255[c]	0.59[y]
Shoulder ER (ND) (N)	70.14 ± 21.66	66.14 ± 27.15	63.67 ± 13.08	0.541[b]	0.02[y]	63.42 ± 13.92	72.44 ± 24.06	0.319	0.45[y]
Knee flexion (D) (N)	205.87 ± 26.83	160 ± 32.51	170.73 ± 48.6	0.006[b]	0.20[y]	186.05 ± 42.53	186.80 ± 42.68	0.965	0.02[z]
Knee flexion (ND) (N)	172.4 ± 27.77	140.79 ± 34.48	157.4 ± 36.41	0.066[b]	0.08[y]	161.05 ± 29.16	165.20 ± 34.23	0.749	0.12[z]
Knee extension (D) (N)	230.27 ± 40.67	227.21 ± 93.86	197.33 ± 44.07	0.118[b]	0.05[y]	209.05 ± 48.16	217.20 ± 38.05	0.623	0.18[z]
Knee extension (ND) (N)	217.47 ± 34.3	236.86 ± 116.61	201.67 ± 28.51	0.438[b]	0.01[y]	202.16 ± 32.00	221.70 ± 30.23	0.121	0.63[y]
Hip extension (D) (N)	240.53 ± 57.15	224.14 ± 77.81	219.33 ± 46.21	0.419[b]	0.01[y]	236.26 ± 55.59	214.70 ± 46.25	0.279	0.42[z]
Hip extension (ND) (N)	248.4 ± 41.77	218 ± 53.82	228.07 ± 69.34	0.289[b]	0.01[y]	248.74 ± 54.16	224.10 ± 65.19	0.361	0.38[z]
Functional strength tests									
CMJ									
Jump height (cm)	22.89 ± 4.85	23.52 ± 3.82	23.53 ± 2.85	0.880[a]	0.77[z]	24.54 ± 2.93	20.20 ± 4.01	0.009	1.24[z]
Peak power (W)	2,873.73 ± 64.70	2,705.43 ± 389.14	2,391.53 ± 479.78	0.040[b]	0.11[y]	2,657.32 ± 640.52	2,478.20 ± 512.16	0.585[c]	0.31[y]
Peak power/BM (W·kg^{-1})	41.73 ± 8.22	40.96 ± 3.39	38.44 ± 3.22	0.171[b]	0.03[y]	41.53 ± 7.20	36.78 ± 2.53	0.006[c]	0.88[z]
Peak landing force (N)	2,848.07 ± 642.85	2,925.21 ± 516.13	2,839.93 ± 786.94	0.930[a]	0.86[z]	2,703.42 ± 631.63	2,962.90 ± 711.93	0.346	0.39[z]
SLJ									
Concentric mean force (ND) (N)	933.27 ± 163.42	928.14 ± 150.55	833.00 ± 117.22	0.118[a]	0.08[z]	879.00 ± 154.20	873.50 ± 142.14	0.924	0.04[z]
Eccentric mean force ND) (N)	716.13 ± 168.67	677.00 ± 123.43	611.00 ± 93.48	0.102[a]	0.12[z]	641.0 ± 105.48	693.30 ± 202.07	0.853[c]	0.32[z]
Jump height (flight time) (ND) (cm)	10.47 ± 2.77	11.414 ± 2.43	11.20 ± 1.65	0.518[a]	0.80[z]	11.49 ± 2.14	9.63 ± 2.19	0.042	0.86[z]
Peak power (ND) (W)	1,634.07 ± 369.89	1,730.93 ± 375.39	1,414.20 ± 224.11	0.038[a]	0.34[z]	1,545.74 ± 311.13	1,461.60 ± 356.61	0.537	0.25[z]
Peak power/BM (ND) (W·kg^{-1})	23.39 ± 4.78	26.24 ± 4.85	22.90 ± 2.44	0.079[a]	0.19[z]	23.77 ± 2.61	22.120 ± 5.40	0.381	0.39[z]
Peak landing force (ND) (N)	2,281.4 ± 518.35	2,166.43 ± 291.92	1,966.47 ± 251.03	0.102[a]	0.12[z]	2,156.63 ± 513.14	2,021.10 ± 216.55	0.555[c]	0.34[z]
Concentric mean force (D) (N)	923.33 ± 171.26	905.14 ± 143.36	828.27 ± 123.77	0.187[a]	0.09[z]	871.00 ± 159.99	864.20 ± 144.30	0.909	0.04[z]
Eccentric mean force (D) (N)	711.20 ± 155.57	658.14 ± 105.04	611.67 ± 92.43	0.092[a]	0.15[z]	641.16 ± 106.11	666.60 ± 181.98	0.836[c]	0.31[z]
Jump height (flight time) (D) (cm)	10.04 ± 3.07	11.11 ± 3.32	11.92 ± 2.03	0.206[a]	0.13[z]	11.63 ± 2.44	9.49 ± 2.83	0.059	0.81[z]
Peak power (D) (W)	1,573.60 ± 424.11	1,544.79 ± 256.19	1,510.07 ± 269.18	0.868[a]	1.63[z]	1,559.95 ± 354.35	1,438.10 ± 280.54	0.849[c]	0.38[z]
Peak power/BM (D) (W·kg^{-1})	21.22 ± 8.01	23.59 ± 4.02	24.47 ± 3.11	0.260[a]	0.25[z]	24.02 ± 3.72	20.15 ± 9.08	0.225	0.56[z]
Peak landing force (D) (N)	2,225.73 ± 38.06	2,157.14 ± 407.14	2,040.93 ± 87.13	0.556[a]	0.88[z]	2,165.95 ± 96.20	2,032.50 ± 220.83	0.668[c]	0.30[z]
Hop test									
Mean active stiffness (N·m^{-1})	24,359.65 ± 8,882.18	32,685.31 ± 34,177.79	22,248.36 ± 6,264.3	0.971[b]	0.05[y]	23,253.5 ± 6,775.3	25,042.3 ± 8,232.4	0.582	0.24[z]
Mean jump height (flight time) (cm)	22.53 ± 10.72	23.58 ± 5.1	22.72 ± 5.58	0.273[b]	0.15[y]	23.52 ± 9.15	20.83 ± 7.37	0.239[c]	0.32[z]
Mean landing RFD (N·s^{-1})	37,658.07 ± 13,844.38	41,906.21 ± 26,658.12	36,965.67 ± 8,229.79	0.996[b]	0.05[y]	38,872.7 ± 10,551.8	35,813.5 ± 12,233.7	0.512	0.27[z]
Mean peak power (W)	6,581.24 ± 7,478.77	4,830.42 ± 1,422.85	4,414.15 ± 1,358.96	0.662[b]	0.03[y]	5,929.62 ± 6,888.92	4,831.1 ± 1,776.76	0.910[c]	0.22[z]
IMTP									
Force at 50 ms (N)	947.79 ± 151.81	860.07 ± 207.53	803.37 ± 277.37	0.219[a]	0.03[z]	862.03 ± 266.94	861.56 ± 167.4	0.729[c]	0.09[z]
Force at 100 ms (N)	1,001.21 ± 154.65	937.00 ± 286.88	914.00 ± 216.15	0.567[a]	0.02[z]	954.11 ± 209.05	946.67 ± 164.86	0.920	0.04[z]
Force at 150 ms (N)	1,058.00 ± 167.40	973.36 ± 262.56	975.27 ± 217.93	0.509[a]	0.01[z]	1,000.74 ± 216.56	1,027.56 ± 159.05	0.716	0.14[z]
Force at 200 ms (N)	1,115.79 ± 182.19	1,024.00 ± 271.11	1,038.60 ± 233.6	0.534[a]	0.02[z]	1,052.16 ± 230.07	1,099.56 ± 163.48	0.539	0.24[z]

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TABLE 1
Group means, *SD*, and *p* value for body composition and musculoskeletal testing for sub-elite female cricket players per player role.*† *(Continued)*

Variables	All-rounder	Batter	Bowler	*p*	Effect sizes	Pace bowler	Spin bowler	*p*	Effect sizes
Peak vertical force (N)	1,517.57 ± 336.28	1,348.71 ± 242.96	1,396.40 ± 296.99	0.307[a]	0.01[a]	1,393.68 ± 268.02	1,531.56 ± 331.75	0.307	0.44[a]
Push up test									
Concentric mean power/BM (W·kg^{-1})	3.13 ± 0.46	3.30 ± 0.49	2.68 ± 0.41	0.111[a]	0.06[a]	2.86 ± 0.66	2.94 ± 0.85	0.824	0.10[a]
Concentric mean velocity (m·s^{-1})	0.46 ± 227.43	0.49 ± 220.00	0.41 ± 208.88	0.135[a]	0.05[a]	0.43 ± 0.09	0.44 ± 0.12	0.809	0.11[a]
Eccentric mean power/BM (W·kg^{-1})	2.56 ± 0.60	3.00 ± 0.94	2.52 ± 0.73	0.245[a]	0.02[a]	2.50 ± 0.73	2.63 ± 0.55	0.635	0.19[a]
Concentric mean force (ND) (N)	227.43 ± 0.73	220.00 ± 0.98	208.88 ± 0.60	0.372[a]	0.01[a]	217.87 ± 35.74	212.58 ± 26.79	0.577[a]	0.17[a]
Concentric mean force (D) (N)	254.54 ± 41.83	226.68 ± 30.85	213.46 ± 26.36	0.010[a]	0.18[a]	235.13 ± 39.83	225.49 ± 43.25	0.409[a]	0.23[a]
Aerobic fitness test									
24-km TT (min)	11:02 ± 1:37	10:32 ± 1:26	11:14 ± 1:26	0.467[a]	0.04[a]	10:57 ± 1:19	11:05 ± 1:31	0.539[a]	0.10[a]

ER = external rotation; ER+ = external rotation; D = dominant; ND = non-dominant; BM = body mass; BMI = body mass index; RMR = resting metabolic rate; RFD = rate of force development; CMJ = countermovement jump; SLJ = single-leg jump; HT = hop test; TT = time trial; n = nation.
†*p* Value classifications: [a]ANOVA; [b]Kruskal-Wallis test; [c]Kolmogorov-all other statistical tests were done using *t*-test). Effect size classifications: [d]Cohen's *d*; [e]Kruskal-Wallis eta squared; [f]ANOVA (omega squared).

Functional Muscle Strength Tests

Functional muscle strength tests for all player roles can be seen in Table 1. The total means for functional muscle strength tests can be seen in Supplemental Digital Content 1 (see Table S2, http://links.lww.com/JSCR/A463). Analysis of the CMJ test indicated a difference ($p = 0.04$, ES = 0.11) in peak power for all-rounders compared with other player roles. For comparisons of CMJ between pace and spin bowlers, there were differences in jump height ($p = 0.009$, ES = 1.24) and peak power normalized with body mass ($p = 0.006$, ES = 0.88). Analysis of the SLJ test indicated no significant differences between the dominant and non-dominant sides for all player roles. Further analysis of the SLJ demonstrated a difference in peak power ($p = 0.038$, ES = 0.34) of the non-dominant leg for batters compared with other player roles. There was a difference during the SLJ for non-dominant leg jump height ($p = 0.042$, ES = 0.86) for pace compared with spin bowlers. For the HT, the all-rounder had the highest peak power and batter the highest jump height compared with other player roles (Table 1).

Pace bowlers had higher jump height, mean landing rate of force development, and peak power than spin bowlers. There were no differences among any player roles for the HT. Analysis of the IMTP indicated increased force generation for the entire test duration to be higher for the all-rounder than other player roles. There were no other differences among the player roles for the IMTP test. Analysis of the push-up test indicated differences between dominant ($p = 0.001$) and non-dominant sides for concentric mean force for all the players. Bowlers had the highest concentric mean power compared with other player roles. Pace bowlers had higher concentric mean force on the dominant side than spin bowlers, but there was no difference between pace and spin bowlers.

Aerobic Fitness Test

The group means of the 24-km TT results for each player role are displayed in Supplemental Digital Content 1 (see Table S2, http://links.lww.com/JSCR/A463). Batters had the lowest 2-km TT times, followed by all-rounders and bowlers. There were no differences between the player roles. Further statistical analysis indicated no difference between pace and spin bowlers.

Discussion

Our study found differences between the physical profiles and demands among various player roles in women's cricket owing to the distinct physical and technical capabilities demanded by each role. The investigation into the anthropometrics demonstrated that female cricket players presented with a BMI of 23.55 ± 3.35 kg·m^{-2}, which is within the healthy mass category compared with other studies on body composition in female athletes (1,17,31). The body mass of sub-elite female cricket players in this study (66.05 ± 10.59) was comparable to that of elite female cricket players (8,18,25). Our study found that all-rounders presented with the highest body mass, BMI and MM%, whereas bowlers presented the lowest body mass, RMR, and MM%. These findings were similar to elite men's cricket, where bowlers presented with lower-body mass than batters (32). Bowlers in our study presented with the highest BF% and batters with the lowest BF%. The overall BF% reported in our study (32.14 ± 6.95) was higher than in other female sports (1). The body composition of players is expected to vary depending on their specific player roles in

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cricket (8,32). Cricket coaches, sports science, and medicine staff should consider implementing individualized training and nutritional strategies to optimize body composition in each player role, thereby supporting their performance and overall health.

The aerobic fitness test showed superior performance by batters, followed by all-rounders and bowlers. The aerobic fitness results in our study for the sub-elite female cricket players present with overall slower time compared with the elite female cricket players (11). Letter et al. (12) found that faster female pace bowlers are superior in all anaerobic capacity measures. It could be indicative that female pace bowlers are outperformed by batters because they might have more aerobic capacity compared with the anaerobic capacity of fast bowlers (11). Our study observed that female batters had lower BF% compared with the bowlers, which aligns with the findings of the aerobic fitness test. Further research is needed to examine the aerobic fitness of players at the sub-elite level and determine the rationale behind the higher aerobic fitness observed in the female batters in our study.

Our study employed shoulder strength tests, push-up tests, and the IMTP to assess upper-body strength. All-rounders demonstrated superior shoulder strength, IMTP, and push-up results compared with other player roles. All-rounders presented with the biggest deficit in dominant IR:ER shoulder strength compared with other player roles. Dominant shoulder IR:ER deficit is linked to a risk of shoulder injury in elite female cricket players (18). Applied practitioners should aim for an IR:ER ratio to reduce the risk of dominant-side shoulder injury by maintaining a 1:1 ratio, specifically in the all-rounder cohort. Interestingly, batters and all-rounders had increased IR:ER shoulder strength in the non-dominant shoulder compared with the dominant shoulder. Future research should investigate the effect of increased shoulder IR:ER shoulder strength on technical performance during batting. Sports science and medicine practitioners should also address these IR:ER deficits and increase overall shoulder strength by implementing shoulder strength and conditioning programs. Another interesting finding in our study is that bowlers presented with the weakest IR:ER shoulder strength compared with other player roles. One potential explanation for the comparatively lower-shoulder strength observed in bowlers, as compared with batters and all-rounders, may be attributed to the repetitive and high-intensity nature of the bowling action. It is possible that bowlers might be more susceptible to shoulder injuries, leading to a reduction in shoulder strength over time. This is just a speculative explanation, and the actual reasons would require further investigation. Previous studies have found a correlation between shoulder extensor strength and ball release speed among sub-elite male pace bowlers (4). Applied practitioners should focus on the current physical preparation of female pace bowlers to enhance their overall muscle strength in the shoulder for improved performance in pace bowling. Additional research is necessary to investigate the relationship between shoulder strength and bowling performance in female pace bowlers.

For lower-body strength testing, our study found increased dominant knee flexion strength compared with the non-dominant side for all player roles. Stakeholders in women's cricket should consider implementing strength and conditioning programs to enhance hamstring muscle strength as a collective effort to reduce the disparity between dominant and non-dominant sides. Further research is needed to investigate this deficit and the effect of hamstring strength on female cricket players' performance. Subsequent examinations of various player roles revealed that all-rounders exhibited higher peak power in the CMJ and HTs in comparison to other player roles. In addition, all-rounders exhibited greater muscle strength in knee flexion and hip extension than batters and bowlers. The scarcity of research on the physical attributes of all-rounders poses challenges in comparing our study's results with the existing literature. It could be suggested that all-rounders dedicate more time to technical and physical development because of the multifaceted nature of their role, in contrast to individuals who solely focus on bowling or batting. The increase in training volume could result in increased muscle strength, power, MM%, and overall body mass, as seen in the results.

In our study, batters outperformed the bowlers in the CMJ. This finding is also evident in elite men's cricket (32). Batters also presented with higher muscle strength and muscle mass compared with bowlers. A notable discovery was that batters exhibited the greatest non-dominant knee extension strength. Investigations for the batters only revealed that the non-dominant leg exhibited greater peak power, concentric force, and jump height than the dominant leg. Batters showed the most significant deficit in knee flexion:extension ratio compared with other player roles. Batters are expected to exhibit greater knee flexion angles and more repetitive knee flexion-to-extension motions during batting (27). In addition to the distinctions above, it is noteworthy that batters exhibited the shortest 2-km TT time, followed by all-rounders and bowlers.

An evident finding of this study was that bowlers had the lowest overall upper-muscle and lower-muscle strength compared with all-rounders and batters. Further investigations suggest that spin bowlers have higher IMTP peak force than pace bowlers. Interestingly, pace and spin bowlers performed equally in the push test, whereas pace bowlers performed better than the spin bowlers in men's cricket (32). The physical demands and biomechanics also differ between spin and pace bowlers, as spin bowlers rely on muscles responsible for producing rotational movements (22,24). This could result in increased focus on enhancing leg strength as part of their physical preparation (15), leading to higher IMTP scores than pace bowlers, as seen in this study. Pace and spin bowlers strongly emphasize their bowling skills, which demand technique over physical strength. By contrast, all-rounders and batters rely on muscular strength for powerful shots, resulting in boundaries (28). Their higher IMTP scores demonstrate that batters and all-rounders may prioritize physical preparation over bowlers to develop upper-body and lower-body strength.

Pace bowlers in our study presented with increased jump height and peak power compared with spin bowlers. Further testing identified a big difference in the non-dominant and dominant leg jump heights during the SLJ for pace bowlers compared with spin bowlers. This finding is also evident in other research comparing male pace and spin bowlers (32). Pace bowlers also presented with higher jump height and peak power than spin bowlers. There were differences in non-dominant leg jump height in pace bowlers compared with spin bowlers, which could be attributed to the bowling biomechanics of pace bowlers. Pace bowlers had reduced knee extension strength but increased hip extension strength compared with spin bowlers. In male fast bowling, bowlers typically aim for minimal knee flexion at front foot contact, as

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a braced knee is advantageous for ball release speed (20). However, researchers have found that female subjects have different bowling biomechanics with a rotational pelvis and trunk rotation technique similar to throwing to generate momentum (3). The pace bowlers in our study present with increased hip strength and reduced knee extension strength. This physical profile fits into the available research suggesting that female pace bowlers use techniques and muscles other than knee bracing to increase ball release speed. However, this is just speculation, and further research is needed to examine the muscles and biomechanics used by female pace bowlers.

This study offers important insights into the physical profiles of sub-elite women's cricket players, but some limitations must be acknowledged. The study sample was limited to a specific geographical area and a small cohort, potentially impacting the generalizability of the findings to other sub-elite female cricket populations. The study's cross-sectional design hinders the establishment of cause-effect relationships between musculoskeletal profiles and performance outcomes. The IMTP results were not normalized to body mass and may influence the results of the study. We suggest that future researchers investigate shoulder strength testing in end ranges to explore the effects of eccentric muscle strength at longer muscle lengths. Also, future research should explore alternative assessments, such as an open kinetic chain test without end-range deceleration, like a medicine ball throw, to expand the scope of research for female cricket players.

This study portrays semielite female cricket players' body composition and physical profile for all player roles. The study aimed to bridge the knowledge gap in women's cricket by providing valuable insights into their physical characteristics and potential areas for strength and conditioning. Our findings indicate a dominant and non-dominant knee flexion strength deficit across all player roles. Moreover, evidence suggests that sub-elite all-rounders exhibit greater muscle strength, power, body mass, and muscle mass than bowlers. Bowlers displayed lower-muscle strength and body and muscle mass yet demonstrated higher jump heights than other player roles. Batters showed superior aerobic fitness capacity relative to other player roles. Considering the unique musculoskeletal profiles of each player role in sub-elite women's cricket is crucial for optimizing performance as these players progress to the elite levels.

Practical Applications

The findings of this study present physical differences between different player roles in women's cricket. The benchmark values from this study will enable applied sports science practitioners to guide physical preparation programs for individual player roles. Applied practitioners should pay special attention to the physical profile of bowlers (pace and spin) because they present with reduced individual muscle group strength and functional muscle strength compared with other player roles. Also, body compositions for sub-elite pace and spin bowlers are compromised compared with batters and all-rounders. Bowlers should be given special consideration to increase muscle mass and strength, including the collaboration of the dietitian and strength and conditioning coach. For all player roles, hamstring muscle strength is significantly reduced in the non-dominant leg. Current physical preparation programs should aim to increase hamstring strength and close the deficit between the dominant and non-dominant sides.

Batters as a group present with the lowest hamstring muscle strength compared with bowlers and all-rounders. All-rounders present with dominant shoulder IR:ER ratio deficit, predisposing them to shoulder injury. Practitioners should aim to increase the IR:ER ratio to 1:1 to reduce injury risk for all player roles, specifically for all-rounders.

Acknowledgments

The authors of this study have no conflict of interest.

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APPENDIX B - INJURY PROFILES IN SUB-ELITE WOMEN'S CRICKET: EXPLORING INCIDENCE, PREVALENCE, NATURE, ONSET AND BODY REGION

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Original Research

Injury profiles in sub-elite Women's Cricket: Exploring incidence, prevalence, nature, onset and body region

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ABSTRACT

Introduction: The rise in participation in sports, like women's cricket, is linked with increased injury risk. Providing high-level longitudinal data is the first step in implementing evidence-based injury prevention strategies.
Design: Prospective cohort study.
Objective: This cohort study aims to describe the injury profiles in sub-elite women's cricket in South Africa during the 2022/23 season.
Methods: Injuries were prospectively recorded using injury surveillance questionnaires, injury surveillance database, and logbooks completed by each team's medical staff. Injury rates were investigated for match and training days, body region, player role, nature, and activity at the time of injury.
Results: Three teams with a total of 44 players (20.86 ± 1.6 years) were included in the study. Injury incidence was 85.23 per 1000 player match days, 15.91 for match time-loss and 69.32 for non-time-loss, with 2.95% of players unavailable for match selection on any day. Fast bowlers had the highest injury incidence. Fielding caused 46.67% of all injuries. Injury incidence was higher in training than in matches. The wrist/hand had the highest injury incidence and caused the most match time-loss.
Conclusion: This study provides valuable insights regarding the current injury rates in sub-elite female cricket players.

1. Introduction

Sustaining an injury has been observed to diminish the likelihood of an individual's selection for professional sport (Hägglund et al., 2013). Injuries result in missed playing time, which reduces the effectiveness of the team's and individual's success in progressing in their career. Various injury prevention models, including the Translating Research into Injury Prevention Practice (TRIPP) framework , were developed to provide a structured approach for sports stakeholders to reduce the risk of injuries (Finch, 2006). The initial phase of the TRIPP model is to create a descriptive injury profile of the population, commonly referred to as injury epidemiology. Subsequently, injury epidemiology will guide the next stage of the injury surveillance framework (Finch, 2006). Epidemiological data can provide valuable insights to relevant stakeholders regarding injury rates, nature, body regions, player roles, and injury-related activities. Further, this information can inform the development of evidence-based injury prevention strategies to be implemented in practice.

Injury epidemiology is a well-researched concept in high-income cricket nations (Orchard et al., 2016). Several injury surveillance studies were published in women's cricket at the elite level cricket. According to a recent systematic review and meta-analysis of women's cricket injury epidemiology the injury incidence was 71.9 injuries per 1000 player hours, 13.3 time-loss injuries per 1000 player hours, and 58.5 non-time-loss injuries per 1000 player hours (Jacobs et al., 2022). According to the review, injury prevalence was higher in elite than

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non-elite levels and shoulder and knee injuries were the most common. Fast bowlers had the highest injury prevalence, and fielders were the most likely to sustain wrist and hand injuries (Jacobs et al., 2022). Warren et al. (2019) investigated injury patterns in elite women's T20 (20 over) cricket in the United Kingdom (UK). The most common injuries were to the shoulder (1.8 injuries per 100 match days), lower back (1.7), and knee (1.7). The hand (1.7%), head/neck (0.8%), and thigh (0.6%) had the highest time-loss prevalence. The most time was lost due to catching-related injuries (2.5%), and throwing-related shoulder injuries were the most common (2.3 injuries per 100 match days) (Warren et al., 2019).

Orchard et al. (2023) conducted a recent epidemiological study on injury rates in elite male and female Australian cricket players. The most common match time-loss injuries in female cricket players were hamstring strains (3.1 injuries per 100 players per season), concussions (2.3), quadriceps strains (2.4), and shin, foot, and ankle stress fractures (2.0). The authors then compared injury rates between male and female cricket players, establishing that males had higher match time-loss injury incidence and prevalence but similar medical attention injury rates. The observed differences in injury patterns between sexes indicate that injury prevention interventions should be adapted to the specific needs of each sex (Goggins et al., 2020; Orchard et al., 2023).

Despite the evidence of injury epidemiology in elite women's cricket (Jacobs et al., 2022; Orchard et al., 2023; Warren et al., 2019), a knowledge deficit is evident at the sub-elite level. There remains a dearth of information regarding injury profiles in women's cricket at the sub-elite level. Therefore, injury prevention strategies implemented at the sub-elite women's cricket are based on either evidence retrieved at the elite level in women's cricket or the sub-elite level of men's cricket. The objective of this study is to establish the incidence and prevalence of injury in sub-elite women's cricket. Findings from this study will effectively guide injury prevention strategies and provide relevant information to stakeholders working with this population.

2. Methods

The STROBE Sports Injury and Illness Surveillance (STROBE-SIIS) (Bahr et al., 2020) and the International Consensus Statement (Orchard et al., 2016) guided the methodology of this longitudinal injury epidemiology study. The STROBE-SIIS checklist is attached in the Supplementary Table S1. Three teams were invited to participate in this study, and 44 female cricket players were voluntarily recruited. All subjects (including guardians of 18-year-olds and younger) gave their written consent for their data to be used in the study. Ethical approval and permission to conduct this study were obtained from Cricket South Africa's (CSA) Medical Research Committee, the respective cricket unions' managers, and the Human Research Ethics Committee (Medical) of the University of the Witwatersrand. The three teams in this study participated in the 20-over and 50-over leagues that ran concurrently for the 2022/23 season.

The season started in September 2022 and continued until November 2022 and followed a month break commencing January 2023. During the month break, the injury surveillance was paused and began when practice re-started in January 2023 and continued till March 2023. Only injuries sustained during the official training and matches or other activities related to preparation for the domestic women's league were used as data for this injury surveillance study. During the season, the players were involved in other cricket leagues (club leagues, tournaments, etc.), and injuries sustained during these matches were not included in this injury surveillance study. A total of 20 matches were played by each of the three teams over a total of 6 months (excluding the 1-month break), ten 50 over and ten 20 over matches.

Injury incidence data were obtained in three ways and compared to validate the data used in this study. First, the three medical teams (physiotherapists and biokineticists) were asked to log injuries over the season for data capturing for this study. Secondly, data was extracted from the injury surveillance system. As part of CSA's national injury surveillance, medical health professionals used a platform, *CricketClinic*, to capture all injury and performance stats over the season. Finally, self-administered baseline and weekly questionnaires were administered using the Research Electronic Data Capture (REDCap) software (Harris et al., 2019). These questionnaires were validated and used in previous injury surveillance studies in the cricket population (Olivier et al., 2015). Self-reported questionnaires were completed at the start of the season and weekly for the duration of the season. The questionnaire aimed to capture weekly self-reported non-time-loss injuries as these are frequently missed if they are not medical attention injuries. All self-reported injuries were discussed with the medical team and team coaches to correlate them with those recorded by the medical team in their logbook or on *CricketClinic*. If the medical team knew of the self-reported injuries, the injury was captured as a self-reported non–time-loss injury. All time-loss injuries reported in this study were injuries recorded by the medical health professionals in their logbooks or on *CricketClinic*. The researchers screened the data on a weekly basis, and had weekly meetings with the medical health professionals to compare self-reported injuries with those documented in the logbook, aiming to identify any time-loss and non-time loss injuries. Additionally, they correlated whether injuries were new occurrences or recurrent instances, i.e., the same injury recurring in the same season.

All definitions used in this study are per the 2016 cricket consensus statement (Orchard et al., 2016). Player roles were classified as batters, bowlers, and wicketkeepers. Further sub-analysis was done for slow bowlers, fast bowlers, and wicketkeepers. All injury incidence or prevalence include "match time-loss" and "non-time-loss" injuries. Match time-loss is an injury that prevents a cricket player from being fully available for match selection, from batting, bowling, or keeping wickets as required by the rules or team captain. Non-time-loss is an injury that does not prevent sports participation (Orchard et al., 2016). In this study, player-reported injuries were cross-checked with the medical team and recorded as non-time-loss if the medical team was unaware of the injury. This study investigated match time-loss injuries, training time-loss injuries and missed match and training days. Training time-loss was not included in any incidence or prevalence calculations but rather in a sub-analysis to compare missed match days with missed training days.

Exposure hours were calculated as a sum of the players in each squad multiplied by the number of match days and reported as player match days or exporsue hours. Player match days were reported in recent cricket epidemiology studies (Goggins et al., 2020; Orchard et al., 2023; Warren et al., 2019) to exclude any confusion for mistaking exposure hours per player or team and for different exposure hours per format of cricket. All injury incidence calculations include both new and recurrent injuries. Injury incidence rates are reported as 1000 player match days for comparisons with other cricket injury epidemiology studies (Orchard et al., 2023). The calculations for injury incidence rates and prevalence proportions is displayed in Table 1 (Goggins et al., 2020; Orchard et al., 2016; Warren et al., 2019).

Table 1
Equations for incidence and prevalence.

Player match days =	daily squad size x number of match days
Player training days =	daily squad size x number of training days
Injury incidence rate =	$\frac{\text{time – loss / non – time – loss injuries x 1000}}{\text{player match days}}$
Match time-loss prevalence =	$\frac{\text{players unavailable for matches x 1000}}{\text{player match days}}$
Match time-loss (per 1000 exposure hours) =	$\frac{\text{match time – loss injuries x 1000}}{\text{match exposure hours}}$
Training time-loss (per 1000 exposure hours) =	$\frac{\text{training time – loss injuries x 1000}}{\text{training exposure hours}}$

2.1. Statistical analyses

The incidence and prevalence rates were analysed using the formulas above as descriptive statistics in Microsoft Excel (Microsoft 365, Microsoft Corporation, Washington, USA).

3. Results

A total of 44 participants with a mean age of 20.86 ± 1.60 years participated in the study. A total of 75 injuries (14 time-loss and 61 non-time-loss) (46 new injuries, 29 recurrent injuries) were recorded over one cricket season (extra descriptive data, including conversions for exposure hours, are available in the supplementary document, Tables S1–S12). Training sessions were 2 hours per session, and matches per team for ODI was 43.3 hours per match per team, and T20 14.7 hours per match per team. Players were exposed to a total of 6336 training hours (3168 player training days) compared to 1740 h in 20 matches (880 player match days). Most injuries occurred during matches (46.67%) and training (49.33%). Time-loss injuries occurred almost equally in training and matches. Illness complaints were initially recorded in this study but only occurred twice during the season and did not result in any time-loss; hence illness is deliberately excluded from this study.

3.1. Injury incidence

The injury incidence of all injuries was 85.23 per 1000 player match days. Time-loss injuries were 15.91 per 1000 player match days and 69.32 for non-time-loss injuries. Match injury incidence in 20 overs was 21.59 per 1000 player match days compared to 50 overs injury incidence of 17.05 per 1000 player match days (Table 2). Injuries resulted in a total 17.11 hours missed for matches and 123.97 hours missed in training. Overall, match time-loss prevalence was 2.95% of players unavailable for selection on any given match day and 29.55 matches missed per 1000 player match days. Training time-loss prevalence was 5.87% of players unavailable to participate in training on any given day. The injury incidence rate for missed training days was 24.62 per 1000 player training days. For time missed due to injury, player match days were converted to exposure hours to compare match and training time-loss. The match time-loss injury incidence rate was 8.05 per 1000 exposure hours, and the training time-loss injury incidence rate of 4.42 per 1000 exposure hours. Wrist/hand injuries caused the most time missed in matches, followed by lower leg and shoulder.

Table 2
Incidence of injuries in sub-elite women's cricket by cricket format and player role (per 1000 player match days).

	Time-loss incidence rate (per 1000 player match days)	Non-time-loss incidence rate (per 1000 player match days)	Injury incidence rate (per 1000 player match days)
All	15.91	69.32	85.23
Per format of cricket:			
All matches	6.82	32.95	39.77
- *T20 match*	*4.55*	*17.05*	*21.59*
- *ODI match*	*2.27*	*14.77*	*17.05*
Training	n/a	n/a	38.64
Other	n/a	n/a	6.82
Per player role:			
All-rounders	6.82	23.86	30.68
Batters (including wicketkeepers)	3.41	22.73	26.14
Bowlers (all)	5.68	22.73	28.41
Per player role (sub-analysis):			
Fast bowlers	7.95	34.09	42.05
Slow bowlers	4.55	12.50	17.05
Wicketkeepers	0.00	6.82	6.82
Batters	3.41	15.91	19.32

3.2. Injuries per body region and player role

Injury incidence (time-loss and non-time loss) per body region can be seen in Table 3. The highest injury incidence occurred in the wrist/hand, knee, and lower leg. The highest time-loss injuries occurred in the lower leg, ankle, and wrist/hand. Fast bowlers had the most match time-loss injuries, followed by slow bowlers. All-rounders had the highest injury incidence compared to bowlers and batters. Further sub-analysis indicated that fast bowlers are more frequently injured when compared to batters, slow bowlers, and wicketkeepers (Table 3).

3.3. Activity, onset and nature of the injury

The nature of injuries per activity of injury is reported in Table 4. Players sustained the most injuries during fielding (46.67%) compared to bowling (25.33%), strength and conditioning (8%), batting (6.67%) and keeping (5.33%). Injuries were more common on the dominant (54.67%) compared to the non-dominant side (32%). The incidence of new injuries (52.27 per 1000 player match days) was higher than that of recurrent injuries in the same season (7.95).

Most new injuries occurred in the wrist/hand and during fielding. The most recurrent injuries occurred in the lower leg, knee and ankle and sustained during fielding and bowling. The most match time-loss injuries occurred during fielding. The incidence of direct contact injuries (61.33%) was higher than non-contact injuries (38.67%). Most recurrent injuries were non-contact injuries (75.86%). Recurrent injuries were linked to injuries sustained in previous seasons (47.83%) rather than the current season (15.22%). Direct contact with the ball had higher incidences (20%) than contact with the ground (12%). Sudden onset injuries (64%) had higher incidences than gradual onset injuries (36%). Medical attention injury incidence was 30.68 injuries per 1000 player match days, including a time-loss of 15.91 injuries per 1000 player match days. All time-loss injuries were medical attention injuries. The highest muscle-related injuries were in the lower leg and shoulder and sustained mainly by fast bowlers. The most joint-related injuries occurred in the wrist/hand and were more prevalent in slower bowlers.

4. Discussion

This study fills a vital research gap regarding injury epidemiology in sub-elite women's cricket. To the authors' knowledge, this is the first study to provide a detailed profile of the incidence rate and prevalence of injuries among the sub-elite female cricket population. The injury incidence rate in 20 over matches was higher (21.59 per 1000 player match days) than in 50 over matches (17.05 per 1000 player match days). The intensity of cricket played during 20 overs is higher than in longer game formats and could be the reason for increased injury incidence, despite the reduced exposure hours compared to 50 overs. In our study, the injury incidence rate for sub-elite women's cricket was 85.23 per 1000 player match days, 15.91 for time-loss and 69.32 for non-time-loss. The injury incidence rate was higher among UK international pathway women's cricket (182.5 per 100 players per year) and UK elite women's cricket (143 injuries per 1000 match days) (Goggins et al., 2020; Warren et al., 2019). Match time-loss was lower for the sub-elite level cricketers in this study compared to elite level women's cricket. Match time-loss in elite Australian women's cricket was 101 injuries per 1000 match days (Orchard et al., 2023) and 2.1 time-loss injuries per 100 match days in elite UK women's cricket (Warren et al., 2019). However, the incidence of match time-loss injuries in this study was higher (15.91 per 1000 players per year) than in UK international pathway women's cricket (7.0 per 1000 player match days) (Goggins et al., 2020). Further, 2.95% prevalence of time-loss injury reported in this study was lower compared to other women's cricket studies; 6.5% in elite Australian women's cricket, 4.6% in UK elite cricket and 4.1% in UK international pathway cricket (Goggins et al., 2020; Orchard et al., 2023; Warren et al., 2019).

Table 3
Incidence of body region injured per player role in sub-elite women's cricket (per 1000 player match days).

	Ankle	Elbow	Head/neck	Hip/groin	Knee	Lower back	Lower leg	Shoulder	Thigh	Wrist/hand
All	9.09	3.41	4.55	6.82	13.64	3.41	12.50	9.09	6.82	17.05
Time-loss	3.41	1.14	0.00	0.00	1.14	1.14	3.41	1.14	1.14	2.27
Non-time-loss	5.68	2.27	4.55	6.82	12.50	2.27	9.09	7.95	5.68	14.77
Per player role:										
Batters	1.14	2.27	2.27	1.14	1.14	0.00	2.27	1.14	2.27	5.68
All bowlers	7.96	1.14	1.14	5.69	9.09	3.41	10.23	6.82	3.41	10.23
- *Fast bowlers*	6.82	1.14	1.14	4.55	5.68	2.27	6.82	5.68	3.41	4.55
- *Slow bowlers*	1.14	0.00	0.00	1.14	3.41	1.14	3.41	1.14	0.00	5.68
Wicketkeepers	0.00	0.00	0.00	0.00	3.41	0.00	0.00	1.14	1.14	1.14

Table 4
Incidence of the nature of injuries per activity of injury in sub-elite women's cricket (per 1000 player match days).

Nature of injury	Fielding	Bowling	Batting	Strength and Conditioning	Wicketkeeping
Muscle	13.64	14.77	4.55	5.68	3.41
Bone/ ligament/ joint	20.45	6.82	0.00	0.00	1.14
Concussion	1.14	0.00	0.00	0.00	0.00
Superficial tissue/ skin	4.55	0.00	1.14	0.00	0.00
All	39.77	21.59	5.68	5.68	4.55

The lower prevalence and incidence of time-loss injuries among sub-elite women's cricket in our study, as opposed to the higher rates reported in the pathway and elite levels, may be attributed to several factors. Firstly, some studies, such as the UK international pathway cricket, (Goggins et al., 2020) report illness in addition to injury, which could be the reason for the higher rates compared to this study. Illness was intentionally excluded from this injury epidemiology study, as in several other cricket studies (Orchard et al., 2010, 2023), as it was not associated with missed match or training time. Another factor could be related to the reduced professionalism at the sub-elite level compared to the elite levels. Only five players per franchise team in this study had formal contracts compared to international pathway cricket, where all players have part-time contracts (Goggins et al., 2020) and elite level, where all players have full-time contracts (Orchard et al., 2023). Without professional contracts and financial support, sub-elite players participate in cricket training and matches based on their work and personal schedules, reducing their commitment to invest in their own and the team's skill development and performance. Less training time and reduced intensity and frequency will lower the risk of injury. The female participants in this study are younger than other women's cricket studies (Orchard et al., 2023; Perera et al., 2019; Warren et al., 2019), and have reduced experience and exposure to skills development as elite cricket players. It's known in different non-elite levels of the sport that these players have limited skill development, match exposure, and physical capacity compared to elite levels of sports (Kelly et al., 2019). Future research in cricket should investigate factors such as bowling speed, training load, match schedule, access to equipment and specialised coaching and the risk of injury at the sub-elite level.

An interesting finding of this study was the higher training time-loss prevalence compared to match time-loss prevalence. There were also more training injury incidences compared to matches. International women's pathway cricket in the UK also reported that the highest medical complaint injuries occurred during training rather than matches (Goggins et al., 2020). The technical demands of traditional net-training sessions exceed that of a typical match for each playing position, specifically for bowlers (Vickery et al., 2018). Training also exposes players to direct contact and non-contact risks. Contact injuries could be more frequent because players are exposed to different dangers during training. The increased contact risk, for example, can be multiple balls in play during training compared to matches as more than one stimulated play is happening during net sessions or more than one ball during fielding sessions. The high incidence of training-related injury could be a reason for the frequency of catching compared to in a match. Players are exposed to different conditions during training, such as other surfaces during fielding and inside and outdoor nets, different playing conditions and intensity, and increased frequency of batting, bowling and fielding that could contribute to non-contact injuries. Besides the higher training injury incidence, match-related injuries caused the most missed time due to an injury. The increased missed time for match-related injuries could be linked to the higher intensity of match play than training. Players are likely to resume earlier to training than matches. A staggered return to matches is expected, as the intensity of cricket is higher in matches than in training, and the risk of injury is higher. Players might go to extremes in matches to take catches, dive to reduce runs, bowl quicker or run faster compared to training.

The highest time-loss injuries occurred in the lower leg and ankle and were sustained mainly by fast bowlers. Also, most non-contact muscle-related injuries occurred in the ankle and lower leg. The high incidence of lower limb injuries reported in this study is similar to other women's cricket studies (Orchard et al., 2023; Perera et al., 2019; Warren et al., 2019). Joint and muscle-related injuries are concerning as these injuries can cause long-term health effects in retired cricket players (Cai et al., 2019; Jones et al., 2018). Female athletes are predisposed to ankle ligament laxity and poor dynamic postural control, increasing the risk of injury (Ericksen & Gribble, 2012). Future research should investigate female health and the effect of these factors on lower limb injury rates specifically at the sub-elite levels.

Fast bowlers had the highest injury incidence (time-loss and non-time-loss), muscle-related injuries and most missed time due to an injury compared to slow bowlers and batters in our study. The kinetic and kinematic risk factors for female fast bowlers could be linked to the high injury rates. Fast bowlers were also the player role with the most injuries in elite women's cricket in Australia (Perera et al., 2019), and the UK(Warren et al., 2019). Evidence suggests that female fast bowlers are exposed to kinematic and kinetic injury risks compared to slower bowlers and other player roles (Stuelcken et al., 2010a, 2010b; Stuelcken & Sinclair, 2009). Female fast bowlers with back pain have increased left lateral flexion relative to the pelvis during the delivery stride compared to bowlers with no lower back pain history (Stuelcken, Ferdinands, & Sinclair, 2010). The distraction force in the shoulder could also contribute to a shoulder injury in female fast bowlers (Stuelcken, Ferdinands, Ginn, & Sinclair, 2010). Kinetic risks are linked with ground reaction forces on the back foot and front foot contact during the bowling action (Stuelcken & Sinclair, 2009). Fast bowlers also have increased training and match volumes compared to other player roles (Petersen et al., 2010; Vickery et al., 2018). Injuries in all-rounders (players with a batting and bowling role in a team) were investigated to determine if this population had a higher incidence rate than only batters or bowlers. As expected, the incidence rate of all-rounders was higher when compared to bowlers and batters.

Almost 50% of injuries during the season were fielding-related

injuries. Fielding was also the activity that caused the most injuries in elite and pathway cricket in the UK (Warren et al., 2019). Catching-related injuries caused the most time-loss injuries in elite T20 women's cricket (Goggins et al., 2020; Warren et al., 2019). Fielding injuries are overrepresented in the female cricket population compared to males. Related to fielding injuries, this study reported that 61.33% of all injuries were direct contact injuries. Contact with the ball resulted in 32.61% of all contact injuries and contact with the ground 19.57%. Other women's cricket epidemiological studies also report a high incidence of contact injuries (Basu et al., 2021; Perera et al., 2019; Warren et al., 2019). Future research should investigate the intensity of fielding activities and compare this to math intensity. For example, fielders need to be exposed to catching and fielding balls that are hit at high speed towards them and need to stop boundary balls by diving. Furthermore, research should investigsate the implementation strategies of ground fielding and diving techniques as several fielding injuries are related to ground impact in this study. This study reports that 8% of all injuries were sustained during strength and conditioning, more than batting-related injuries. Future studies must explore the nature of training modalities specifically at the sub-elite level to explore whether strength and conditioning pertain to a risk of injury in sub-elite women's cricket.

The high incidence of wrist/hand injuries compared to other body regions.among this sub-elite cohort is concerning. The highest direct contact and joint-related injuries also occurred in the wrist/hand. Most of these injuries were sustained during fielding. Other women's cricket studies also reported a high incidence of wrist/hand injuries compared to other body regions (Goggins et al., 2020; Perera et al., 2019; Warren et al., 2019). There was also more acute onset than gradual injuries and more new injuries than recurrent injuries among this sub-elite women's cricket population. The high incidence of acute onset and new injuries can be linked to the high incidence of direct contact injuries. Most direct contact injuries occurred with the ball or the ground during fielding. Female cricket players could have developed catching and ground fielding techniques predisposing them to injury. Cricket players face several risks during fielding; contact with the ball, falls, boundary rope, and contact with the ground. Research is needed to identify fielding related factors such as hand-eye coordination and visual reaction time to reduce the risk of contact injury at the sub-elite level. Research has indicated long-term osteoarthritis and other health outcomes in past elite cricket players (Jones et al., 2018). Osteoarthritis, total hip and knee replacements are more prevalent in former cricket players compared to the general population (Cai et al., 2019). Reducing the number of direct contact injuries in women's cricket is vital for better long-term health outcomes after a cricket career and an indication for future research.

A limitation of this study is the small population size and potential consequences on external validity. Another limitation is the lack of detailed information regarding the cohort's playing history, age of commencement in cricket, number of seasons played at the sub-elite level, and involvement in additional sports, which could potentially impact injury rates and limit the generalisability of the findings. A strength of this study is the rigorous methodology, including three data sources to verify the data collection and reporting. All self-reported injuries were confirmed with medical team members. Another strength of this study is that all injuries sustained during matches and training and time missed for these were reported for an objective overview of all injuries sustained in sub-elite women's cricket. This study is the first to examine injury profiles in sub-elite women's cricket in South Africa. This study provided a comprehensive profile of injuries in this population by examining the injury's nature, onset, activity, player roles, body region, and time missed due to injury.

5. Conclusion

This study provides evidence-based injury rates in sub-elite women's cricket that can be used as the first step to guide injury prevention programs, specifically in South African women's and other sub-elite women's cricket populations. Injury incidence for sub-elite women's cricket (including time-loss) is lower than at elite levels. Fast bowlers had the highest injury incidence. Fielding was the activity that caused the most injuries. Wrist/hand had the highest incidence and caused the most missed time due to injury. Future research should focus on reducing the incidence of direct contact injuries, particularly during fielding. Research is needed to investigate catching techniques and ground movements during fielding to identify possible injury risk factors.

Disclosure statement

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CRediT authorship contribution statement

Jolandi Jacobs: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. **Benita Olivier:** Conceptualization, Methodology, Supervision, Visualization, Writing – original draft, Writing – review & editing. **Corlia Brandt:** Conceptualization, Methodology, Supervision, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data for this article can be found in Appendix A.

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APPENDIX C - ANTHROPOMETRIC AND BIOMECHANICAL FACTORS IN ELITE MALE AND FEMALE FAST BOWLERS

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Anthropometric and biomechanical factors in elite male and female fast bowlers

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ABSTRACT

Researchers have extensively studied the biomechanics and anthropometrics of fast bowling in men's cricket, but there is still limited research in women's cricket. This study describes and compares the anthropometric qualities and bowling biomechanics between elite male and female fast bowlers. An inertial measurement system was used to collect three-dimensional biomechanical data for 20 elite fast bowlers (13 males and seven females). Kinematic data was captured at one step before back foot contact, back foot contact, front foot contact, ball release to one step after ball release. Anthropometric measurements included body segment lengths, mass, body fat (BF%) and muscle mass (MM%). The student *t*-test and Mann-Whitney *U* test were used for analyses. Hotelling's T2 statistic was calculated to control Type I error during multiple comparisons ($p = 0.045$). Males and females differed in overall height, limb length, BF% and MM%. Females presented with slower ball release speeds ($p = 0.001$). Biomechanically, the females were more front-on when approaching the delivery stride and then initiated pelvis and trunk rotation during the delivery stride, not seen in the males. Females and males have a similar magnitude of trunk side-flexion, but females present with a different strategy than males ($p = 0.038$). Females presented with increased front knee extension at ball release ($p = 0.05$). The findings from this study emphasise the differences between male and female fast bowlers and suggest that the coaching principles used in male fast bowling may not be relevant to female fast bowlers.

1. Introduction

The performance of fast bowlers is mainly linked to their ball release speed, as increasing ball release speed increases the difficulty for batters to score runs or defend their wicket. Hence, fast bowlers and their coaches constantly try to increase ball release speed by addressing bowling kinematics and techniques (Worthington et al., 2013). Research on fast bowling biomechanics and anthropometrics in men's cricket (Wormgoor et al., 2010, Portus et al., 2004, Glazier et al., 2000, Worthington et al., 2013) is widely researched. Still, the same cannot be said for female fast bowling.

Several studies have investigated the relationship between biomechanics and ball release speed in men's cricket (Wormgoor et al., 2010, Portus et al., 2004, Glazier et al., 2000). In the last decade, research on male fast bowling indicates that ball release speed is linked to faster run-up speeds (Kiely et al., 2021; Worthington et al., 2013), reduced time at the back foot contact (BFC) (Kiely et al., 2021), braced front knee during front foot contact (FFC) (Worthington et al., 2013), greater trunk flexion and delayed onset of shoulder counter-rotation (Worthington et al., 2013). Besides kinematic factors in male fast bowlers, anthropometric qualities also play a role in ball release speed. Previous research (Glazier et al., 2000) suggests increased shoulder-to-wrist and total arm length may be associated with increased ball release speed in male fast bowlers. However, recent studies suggest that no single anthropometric characteristic or body somatotype variable influences the ball release speed of male fast bowlers (Salter et al., 2007, Wormgoor et al., 2010).

Bowling biomechanics are found to be different between male and female fast bowlers, and it could be the cause for the slower ball release

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speeds seen among females (Felton et al., 2019). Research on female fast bowling indicates that females generally have shorter run-ups than male fast bowlers, resulting in slower ball release speeds (Savage and Portus, 2002, Lucente et al., 2021). More recently, Felton et al. (2019) discovered that female fast bowlers have slower run-up speeds and less whole-body momentum, resulting in a slower ball release speed and biomechanical differences compared to male fast bowlers. Felton et al. (2019) indicated that female fast bowlers use more thoracic and pelvis rotation to compensate for the loss of whole-body momentum.

Besides bowling biomechanics, anthropometric qualities are also unique for female fast bowlers. According to Savage and Portus (2002), female fast bowlers have slower ball release speeds than their male counterparts due to shorter upper and lower limb lengths and lower muscle strength. Stuelcken et al. (2007) suggested that female fast bowlers had slower ball release speed than males due to the more endomorphic body build than males' mesomorphic body type. Letter et al. (2022) further indicated that ball release speed is affected by lower and upper body strength in female fast bowlers. The findings above suggest that certain factors influencing bowling performance are sex independent, with implications for both male and female fast bowlers.

There is still a significant gap in scientific knowledge around female fast bowlers' biomechanical technique and factors contributing to ball release speed. It is unknown if the knee angle at FFC indicates increased ball release speed for females as it is for males or if shoulder counter-rotation affects the ball release speed in female cricket players. There is limited research investigating if shorter limb lengths or body types are associated with reduced ball release speeds in females compared to males. This study will shed light on the potential anthropometric and biomechanical factors contributing to differences in fast bowling performance between elite male and female cricketers. Understanding these differences could lead to a more individualised approach, including more tailored training programs for both male and female fast bowlers, promoting sex-specific sports advancements. To gain a better insight into biomechanics and anthropometric qualities for female fast bowlers, this study describes and compares the differences between elite male and female fast bowlers in South Africa in terms of these constructs.

2. Methods

2.1. Study design and setting

This was a cross-sectional, quantitative study. Data collection occurred at the respective cricket unions during the 2022/2023 season for elite male and female fast bowlers.

2.2. Participants

Elite male and female fast bowlers were recruited from the elite fast bowling cohort of Cricket South Africa (CSA). Twenty injury-free bowlers, 13 male and seven female fast bowlers, agreed to participate in this study. Ethical approval was granted by CSA's Medical Research Committee permission and the Human Research Ethics Committee (Medical) of the University of the Witwatersrand. Before the start of the study, all participants and guardians of those under the age of 18 provided written consent for using their data in this study.

2.3. Instrumentation and outcome measures

The researchers gathered 3D biomechanical data using an inertial measurement unit (IMU) and an analysis system. The Xsens (MVN Link Biomech, Xsens Technologies B.V., Enschede, Netherlands) system consists of a full-body human measurement system recording at 240 Hz using biomechanical models and sensor integration algorithms. The Xsens hardware comprises a lycra suit with markers for each of the 17 IMU sensors (Roetenberg et al., 2013). The MVN Analyse software was used to capture biomechanical data, which was subsequently synchronised by an algorithm into corresponding joint and segment angles. A comparison was made between the joint angles in the sagittal plane and non-sagittal torso-related angles obtained from Xsens MVN and those obtained from a 3D marker-based motion capture system. Xsens is a validated biomechanical system (Zhang et al., 2013), and a pilot study was conducted prior to the initiation of the present study.

2.4. Data collection

Anthropometric measurements were taken before the commencement of the biomechanical analysis. First, the anthropometrics measurement was conducted per the calibration requirements of the Xsens system. The metrics represent the overall stature of an individual, comprising the total height, shoulder height, shoulder width, arm span, hip height, hip width, knee height, ankle height, shoe height, and foot length (Suppl. Table S1). The body measurements were then logged into the Xsens software. Secondly, body composition measurements were taken on the Omron (Model OM-BF511) body composition scale (Omron BF306, Omron Healthcare, Inc., Vernon Hills, IL) (Lintsi et al., 2004). Data from the scale comprised various measurements such as mass, body mass index (BMI), body fat percentage, muscle mass percentage, and resting metabolic rate (RMR).

Before conducting the 3D bowling analysis, all participants were directed to engage in a complete warm-up routine similar to a match warm-up. Subsequently, the bowler then put the lycra suit on. The IMUs were connected and calibrated in the N-pose (arms neutral alongside the body) and walking as an activity (Roetenberg et al., 2013). After a successful calibration, the bowlers were instructed to bowl six deliveries at match speed with a 156 g cricket ball for males and a 142 g ball for females. Bowling accuracy was measured using a target behind the wickets as used by Portus et al. (2000). The velocities at which the bowlers released the balls were recorded using a radar gun (Stalker ATS®, Texas, USA) that was situated 180° behind the ball release point. The Xsens software was utilised to capture three-dimensional biomechanical data during the trials.

2.5. Data reduction and statistical analysis

Ninety-eight bowling trials (61 for males and 37 for females) were successfully extracted from the Xsens software. The data analyst calculated the biomechanical angles for all bowling trials according to the definitions and movement planes (Table 1) in MATLAB (v 2022b, MathWorks, Natick, MA). Key segments of each bowling trial were identified for analysis, i.e. one step before back foot contact, back foot contact (BFC), front foot contact (FFC), ball release (BR) and one step after ball release (Fig. 1).

Before-BFC was defined as the time interval of 100 timesteps (100hz) from before BFC and identified the maximum combined acceleration of the front leg in the interval. BFC was identified as occurring four frames (0.017 s) before the peak resultant back tibial acceleration that occurred within 100 frames (0.42 s) prior to front foot contact (Olivier et al., 2023, Lamb et al., 2022). FFC was identified as occurring three frames (0.013 s) before the peak resultant front tibial acceleration that occurred within 300 frames (1.25 s) prior to the overall (for the trial) peak resultant forearm acceleration. BR was identified as occurring at the instant of the peak resultant bowling forearm acceleration that was recorded within 50 frames (0.21 s) after front foot contact (Olivier et al., 2023, Spratford et al., 2015). One step after BR was identified as five frames (0.021 s) occurring before the peak resultant back tibial acceleration that occurred within 125 frames (0.52 s) after ball release (Olivier et al., 2023). The BFC phase was defined as beginning at BFC and ending at FFC. The FFC phase was defined as beginning at FFC and ending at BR. The follow-through phase began at BR and ended at the one step after BR. The total movement was defined as the sum of these three phases. Three-dimensional data time stamps for each segment mentioned above were extracted for further data analysis. Definitions

Table 1
Definitions for biomechanical variables.

Biomechanical variable	Definition	Xsens MVN System movement variable*
Time duration	The measurable length of a phase of the bowling action.	N/A
Trunk side-flexion	The biomechanical variable represents the lateral bending of the trunk. The trunk is the segment between the shoulders (C7 or T1) and L5. Trunk side-flexion to the left was captured as negative degrees, and to the right, it was positive.	Joint Angles ZXY or XZY were used to capture trunk side-flexion. The rotation around the Z-axis (for ZXY) or X-axis (for XZY) represented trunk side-flexion.
Trunk rotation	The axial turning of the trunk relative to the pelvis. The trunk is defined as the segment between the shoulders (C7 or T1) and L5, and this rotation is also referred to as the pelvis-shoulder separation angle.	Joint Angles ZXY or XZY were used to capture trunk rotation. The rotation around the Y-axis (for both ZXY and XZY) represented trunk relative to the pelvis.
Pelvis rotation	The rotational movement of the pelvis relative to the lower back (L5).	Joint Angles ZXY or XZY were used to capture pelvis rotation. The rotation around the Z-axis (for ZXY) or X-axis (for XZY) represented the rotational movement of the pelvis.
Centre of mass	The centre of mass is a point within the pelvis representing the average location of the body's mass.	N/A
Hip flexion and extension	The biomechanical movements of the hip joint that involve a decrease (flexion) or an increase (extension).	Joint Angles ZXY or XZY were used to capture hip flexion and extension. The rotation around the Y-axis (for both ZXY and XZY) represented hip flexion and extension.
Knee flexion and extension	The biomechanical movements of the knee joint that involve a decrease (flexion) or an increase (extension).	Joint Angles ZXY or XZY were used to capture knee flexion and extension. The rotation around the Y-axis (for both ZXY and XZY) represented knee flexion and extension.
Ball release speed	The velocity at which the cricket ball is released during the bowling action.	N/A
Shoulder counter rotation	The transverse clockwise movement (away from the batter) of the shoulder alignment was recorded between back foot and front foot contact.	Joint Angles ZXY or XZY were used to capture shoulder counter rotation. The rotation around the Z-axis (for ZXY) or X-axis (for XZY) represented the transverse movement of the shoulder alignment.

for each biomechanical plane are listed in Table 1.

All statistical analyses, including means, data distribution (standard deviation (SD)), standard error, and significance, were carried out using SPSSv.28 (SPSS Corporation, USA). The trials for each player were grouped, and a mean for each player (13 males and seven females) was calculated. The means of the trials for each player reduced the standard error during the analyses. The data were assessed for normality using Levene's Test for Equality of Variances to compare means. Hotelling's T^2 statistic was calculated to control Type I error between the two sexes for differences in biomechanics ($p = 0.045$). The student *t*-test was used to analyse the independent variables, and if any parameters violated the normality assumption, the non-parametric Mann-Whitney *U* test was conducted instead. Cohen's d and η^2 classification were used to determine the effect sizes of parametric and non-parametric tests, respectively. The effect sizes were grouped as small effect sizes < 0.2, medium 0.2–0.8, and large > 0.8, indicating the strength of the relationship or the practical significance of the observed effect. The anthropometric values were standardised using z-score normalisation, subtracting the mean and dividing by the standard deviation to transform each value. The distribution has a mean of 0 and a standard deviation of 1.

3. Results

3.1. Participant characteristics

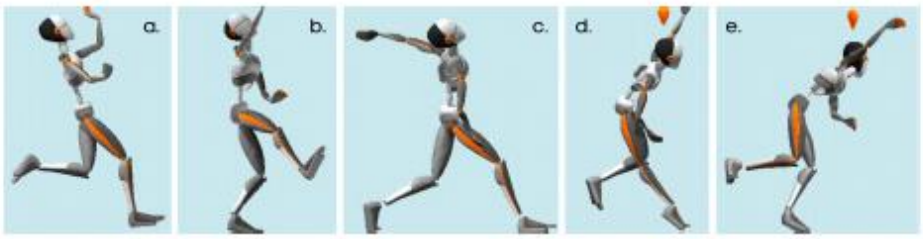
Seven female fast bowlers and 13 male fast bowlers with a mean (SD) age of 22.86 (3.93) years for females and 23.77 (3.68) years for males participated in this study. All 20 participants were right-handed fast bowlers.

3.2. Anthropometric qualities

Anthropometric measurements are indicated in Table 2. Significant differences were found for the following variables: mass, height, BF%, MM% and RMR. Males had increased body measurements with larger effect sizes compared to females.

3.3. Bowling biomechanics

The bowling biomechanics data are indicated in Table 3. Males had increased ball release speed compared to females. Females took more time than males for all phase lengths from one bowling phase to another (Fig. 2A). Before-BFC, female fast bowlers had reduced trunk and pelvis rotation and decreased hip and knee flexion of the front leg (Fig. 2C–H). There were differences at BFC for trunk side-flexion (Fig. 2B) and knee flexion of the back leg (Fig. 2H). At FFC, females had longer phase lengths to ball release than males. Females also had reduced trunk side-flexion and knee flexion of the back leg, while males had increased knee flexion of the front leg. At BR, females presented with reduced knee



a. before back foot contact, b. back foot contact, c. front foot contact, d. ball release, e. one step after ball release

Fig. 1. Each time point of the bowling action (images screenshots from Xsens software) *a. before back foot contact, b. back foot contact, c. front foot contact, d. ball release, e. one step after ball release.*

Table 2
Group means and differences of body measurements and anthropometric qualities for elite male and female fast bowlers.

Variables	Female Mean (SD)	Male Mean (SD)	Mean Difference (SE)	Normalisation		P-value	Effect sizes
				Female Mean (SD)	Male Mean (SD)		
Age (years)	22.86 (3.93)	23.77 (3.68)	0.91 (1.77)	−0.62 (3.93)	0.48 (0.75)	0.612	0.24
Mass (kg)	67.30 (11.37)	81.82 (11.21)	14.52 (5.28)	−0.91 (0.83)	0.92 (0.76)	0.013	1.29
Height (m)	165.50 (9.04)	184.77 (7.58)	19.27 (3.80)	−1.64 (0.73)	1.62 (0.68)	0.481	2.38
BMI (kg/m^2)	24.97 (2.49)	24.45 (2.47)	0.52 (1.16)	0.26 (0.77)	−0.26 (0.77)	0.661	0.21
Body fat %	35.46 (5.70)	19.36 (7.26)	16.10 (3.18)	1.15 (0.86)	−1.15 (1.00)	<0.001	2.37
Muscle mass %	26.41 (1.97)	39.84 (4.20)	13.42 (1.69)	−1.38 (0.89)	1.38 (0.95)	<0.001	3.72
RMR (kcal)	1381.86 (154.55)	1804.54 (137.20)	422.68 (67.14)	−1.50 (0.91)	1.50 (0.85)	<0.001	2.95
Shoulder height (mm)	141.71 (8.83)	158.46 (6.17)	16.75 (3.36)	−1.61 (0.83)	1.61 (0.80)	<0.001	2.34
Shoulder width (mm)	38.57 (1.27)	41.54 (2.73)	2.97 (1.10)	−1.54 (0.85)	1.54 (0.89)	0.015	1.27
Arm span (mm)	167.64 (8.29)	187.77 (5.31)	20.13 (3.03)	−1.55 (0.84)	1.55 (0.87)	<0.001	2.99
Hip height (mm)	87.64 (6.39)	101.46 (5.30)	13.82 (2.67)	−1.63 (0.83)	1.63 (0.87)	<0.001	2.43
Hip width (mm)	23.86 (1.35)	28.15 (2.44)	4.30 (1.00)	−1.70 (0.85)	1.70 (0.87)	<0.001	2.01
Knee height (mm)	46.07 (3.52)	52.46 (3.67)	6.39 (1.70)	−1.39 (0.84)	1.39 (0.85)	<0.001	1.77
Ankle height (mm)	7.43 (2.76)	11.62 (1.33)	4.19 (0.90)	−1.07 (0.86)	1.07 (0.86)	<0.001[b]	0.68*
Shoe height (mm)	2.93 (0.19)	3.23 (0.44)	0.30 (0.18)	−1.54 (0.76)	1.54 (0.91)	0.08[b]	0.16*
Foot length (mm)	27.86 (1.57)	29.38 (1.04)	1.53 (0.58)	−1.59 (0.87)	1.59 (0.87)	0.018	1.23

[a]t-test, [b]Mann-Whitney U test. Effect sizes were calculated by Cohen's d (parametric) and *η^2 (non-parametric).

flexion of the front leg compared to males (Fig. 2G). At one step after BR, females showed increased trunk and pelvis rotation compared to males. Females had increased hip flexion and decreased knee flexion of the front leg compared to males (Fig. 2E&G).

4. Discussion

This study aimed to describe and compare the anthropometric qualities and bowling biomechanics of female fast bowlers, highlighting distinctions from male counterparts to emphasise the need for a unique approach when working with female players. The unique biomechanical and anthropometric discrepancies can be further investigated to guide coaches to implement individualised training techniques for female fast bowlers, as the coaching strategies used for male fast bowlers cannot be replicated for females.

The anthropometric variables between males and females displayed several key observations. Notably, the variables related to body composition, such as BF%, MM% and RMR, show substantial differences between the two sexes. Females exhibited higher body fat percentages and lower muscle mass percentages compared to males. Additionally, the RMR is significantly lower in females. Furthermore, height-related variables, such as shoulder height, arm span, hip height, and knee height, all demonstrate considerable distinctions, with males consistently displaying larger measurements. These findings underscore the importance of considering sex-specific variations in anthropometric characteristics and suggest potential areas for targeted interventions or further investigation. Although these differences between males and females are not unique to cricketers (Santos et al., 2014), they may influence the ball release speed attained during the bowling action. Previous researchers discovered strong correlations between arm length and overall body mass, leading to increased ball release speed in men's cricket (Glazier et al., 2000, Pyne et al., 2006). Analyses of body compositions in this study indicated high BF% and low MM% for female fast bowlers. These findings are similar to previous research on elite fast bowlers, where females were more endomorphic and less mesomorphic than males (Stuelcken et al., 2007). Savage and Portus (2002) suggested that female bowlers have reduced muscle strength and shorter upper limbs, which could be linked to slower ball release speeds compared to males. Future research should investigate if the differences in anthropometric measurements, such as arm span, hip height and overall height, BF% and MM%, could be a factor for the biomechanical differences we observe in female fast bowlers.

The female fast bowling biomechanics in this study vary from the male fast bowlers. Female fast bowlers presented with longer phase lengths from before-BFC to one step after BR, which indicates reduced linear momentum for female fast bowlers as they progress through the delivery stride. Another finding at before-BFC indicated that females presented with reduced hip flexion of the back leg, which could be linked to the reduced linear momentum generated in their bowling action. Notably, males, leveraging increased hip flexion of the back leg, stride forward to BFC with more linear momentum. In contrast, females in this study demonstrate slower ball release speeds (101.30 ± 5.63 km/h) than their male counterparts. This divergence challenges conventional expectations, as previous research has often suggested that female fast bowlers adopt techniques resembling those of their male counterparts. Contrary to this expectation, our findings align with Savage and Portus (2002), who found that female fast bowlers have slower run-ups than males and findings by Felton et al. (2019) that females have less linear momentum as they approach the delivery stride. Thus, our findings are similar to previous research suggesting that female fast bowlers have reduced linear momentum during the delivery stride and reduced ball release speeds compared to male fast bowlers (Felton et al., 2019).

This study identified that females initiated more trunk and pelvis rotation during their bowling action. Females initially presented with reduced pelvis and trunk rotation compared to males at the point of before-BFC, indicating a front-on approach for females as they approach the delivery stride. The females then presented with more trunk and pelvis rotation at the phase length from BFC to FFC. It is also interesting to note that the females' phase lengths from BFC to FFC were longer than males. The additional time available can be used to generate rotation in the trunk and pelvis. No significant increase in trunk or pelvis rotation or trunk side-flexion was observed during FFC to BR. During BR to one step after BR females presented with increased rotation of the trunk and pelvis compared to males. This could be because of the transverse momentum generated from BFC to FFC. The transverse momentum pushes the females into further rotation after the delivery stride, similar to a wind-up and wind-down effect. Felton et al. (2019) suggested that females have less linear momentum when arriving at the crease and compensate by using large rotator muscles to generate momentum. Similar to these findings, the females in our study could use the increased rotational strategies to increase transverse momentum during their delivery stride.

There were notable biomechanical differences between male and female fast bowlers at the front leg. Males presented with increased hip flexion of the front leg at BFC and decreased hip flexion at BR (Fig. 2E) compared to females. This finding suggests that males use more hip extension of the front leg from BFC to BR, indicating that males rely on the flexion to extension movement of the front hip compared to females

Table 3
Group means and standard deviation of biomechanical variables for elite male and female fast bowlers.

Variables	One step before BFC				BFC				FFC			
	Female Mean (SD)	Male Mean (SD)	P-value	Effect sizes	Female Mean (SD)	Male Mean (SD)	P-value	Effect sizes	Female Mean (SD)	Male Mean (SD)	P-value	Effect sizes
Time duration (ms)	75.17 (10.15)	71.13 (15.80)	0.551[a]	0.20	40.78 (4.60)	39.42 (7.33)	0.664[a]	0.28	58.90 (20.98)	46.59 (22.60)	0.250[a]	0.56
Trunk side-flex (°)	−1.8 (4.19)	−0.41 (3.26)	0.420[a]	0.39	4.04 (2.21)	0.31 (4.88)	0.073[a]	0.89	−3.44 (3.83)	−7.71 (4.16)	0.038[a]	1.05
Trunk rotation (°)	17.92 (8.06)	22.30 (6.68)	0.209[a]	0.61	13.40 (8.51)	15.14 (6.39)	0.612[a]	0.24	21.84 (6.41)	19.88 (9.11)	0.621[a]	0.24
Pelvis rotation (°)	8.11 (3.60)	10.08 (2.99)	0.205[a]	0.62	6.00 (3.92)	6.80 (2.84)	0.604[a]	0.25	9.98 (2.89)	9.10 (4.11)	0.658[a]	0.21
COM (m)	1.02 (0.47)	1.11 (0.17)	0.208[a]	0.61	0.98 (0.05)	1.12 (0.04)	<0.001[a]	3.11	0.84 (0.04)	0.97 (0.08)	0.001[a]	1.80
Hip flex/ext (FL) (°)	1.21 (8.77)	3.68 (15.21)	0.699[a]	0.18	49.77 (12.93)	56.40 (7.52)	0.160[a]	0.69	50.04 (5.70)	52.41 (7.44)	0.474[a]	0.34
Hip flex/ext (BL)(°)	41.96 (15.59)	54.49 (15.09)	0.097[a]	0.82	16.25 (6.40)	15.78 (6.40)	0.879[a]	0.07	−2.41 (2.79)	−1.62 (6.19)	0.754[a]	0.15
Knee flex (FL) (°)	31.82 (6.92)	39.16 (14.83)	0.501[b]	0.02*	51.32 (6.68)	49.01 (13.01)	0.722[a]	0.17	17.76 (6.64)	14.70 (7.94)	0.398[a]	0.41
Knee flex (BL) (°)	114.24 (18.06)	106.01 (17.32)	0.331[a]	0.47	32.64 (8.78)	21.76 (13.39)	0.070[a]	0.90	49.16 (6.76)	55.67 (7.58)	0.074[a]	0.89

Variables	BR				One step after BR			
	Female Mean (SD)	Male Mean (SD)	P-value	Effect sizes	Female Mean (SD)	Male Mean (SD)	P-value	Effect sizes
Time duration (ms)					98.69 (12.54)	102.68 (22.12)	0.613[a]	0.21
Trunk side-flexion (°)	−2.62 (14.34)	−2.62 (11.72)	1.000[a]	0.00	12.67 (7.84)	13.54 (5.88)	0.782[a]	0.13
Trunk rotation (°)	22.04 (12.12)	18.95 (10.58)	0.560[a]	0.28	28.93 (4.99)	21.18 (9.69)	0.104[b]	0.14*
Pelvis rotation (°)	10.26 (5.45)	8.74 (4.93)	0.533[a]	0.30	13.52 (2.53)	9.94 (4.56)	0.037[a]	0.89
COM (m)	0.87 (0.06)	1.00 (0.08)	0.002[a]	1.70	0.85 (0.06)	0.99 (0.08)	0.002[a]	1.71
Hip flex/ext (FL) (°)	45.55 (15.37)	40.92 (10.37)	0.431[a]	0.38	30.40 (5.82)	14.86 (13.19)	0.008[b]	0.37*
Hip flex/ext (BL) (°)	52.51 (15.13)	51.82 (14.88)	0.878[a]	0.07	66.67 (5.44)	59.75 (16.75)	0.192[a]	0.49
Knee flexion (FL) (°)	13.09 (11.71)	16.13 (19.49)	0.050[a]	0.27	21.61 (13.97)	42.09 (16.1)	0.011[a]	1.33
Knee flexion (BL) (°)	50.36 (20.11)	65.89 (27.19)	0.166[a]	0.62	35.26 (5.50)	39.32 (13.17)	0.451[a]	0.36
Ball release speed (km/h)	101.30 (5.63)	131.90 (5.11)	<0.001[a]	5.78				
Shoulder counter rotation (°)	21.46 (15.57)	12.25 (9.16)	0.191[b]	0.09*				

Back foot contact (BFC), front foot contact (FFC), ball release (BR), front leg (FL), back leg (BL), flexion (flex), extension (ext).
[a]*t-test*, [b]*Mann-Whitney U test. Effect sizes were calculated by Cohen's d (parametric) and* $*\eta^2$ *(non-parametric).*

who maintain somewhat of a similar magnitude of hip flexion from BFC to BR. Felton et al. (2019) also noted a difference in timing in hip extension between male and female fast bowlers but at the back leg. Further research is warranted to investigate if the magnitude of hip flexion/extension is a performance factor for female fast bowling, as this differs from the action we see in males. Another difference was noted at the knee joint of the front leg. Females presented with decreased knee flexion from FFC to BR compared to males, who presented with increased knee flexion from FFC to BR. Females also presented with reduced front knee flexion (more extended knee) at BR compared to males. It could be suggested that the females in our study used a knee extension technique at the front leg from FFC to BR (Fig. 2E), in contrast to males who used a hip extension technique of the front leg from BFC to BR (Fig. 2G). A straighter knee throughout the front foot contact phase is associated with faster ball release speeds (Worthington et al., 2013). However, Olivier et al. (2016) found that bowlers can potentially enhance their BR speed and remain injury-free over a season by maintaining a flexed knee throughout the bowling action. Future studies should investigate the knee angles of the front leg at FFC and BR and the association with ball release speed and knee injury risk in female fast bowlers.

A noteworthy finding of this study was the disparity in trunk side-flexion between males and females (see Fig. 2B). Females presented with left trunk side-flexion compared to a neutral (upright) trunk position of the males at before-BFC. Females then transition to side-flexion to the right, whereas males maintain a neutral (upright) trunk at BFC. Males and females present with increased trunk side-flexion towards the left at FFC. Interestingly, the magnitude of left trunk side-flexion from BFC to FFC was similar for both sexes. However, males exhibited an augmented total magnitude of right side trunk flexion at FFC due to their neutral (upright) trunk position at BFC, in contrast to females who initially presented with left side trunk flexion at BFC. This technique could be beneficial for the females as previous research indicated that female fast bowlers had proportionally longer trunk lengths than male fast bowlers (Stuelcken et al., 2007) and could be an anthropometrical and biomechanical advantage for the females to use right to left trunk

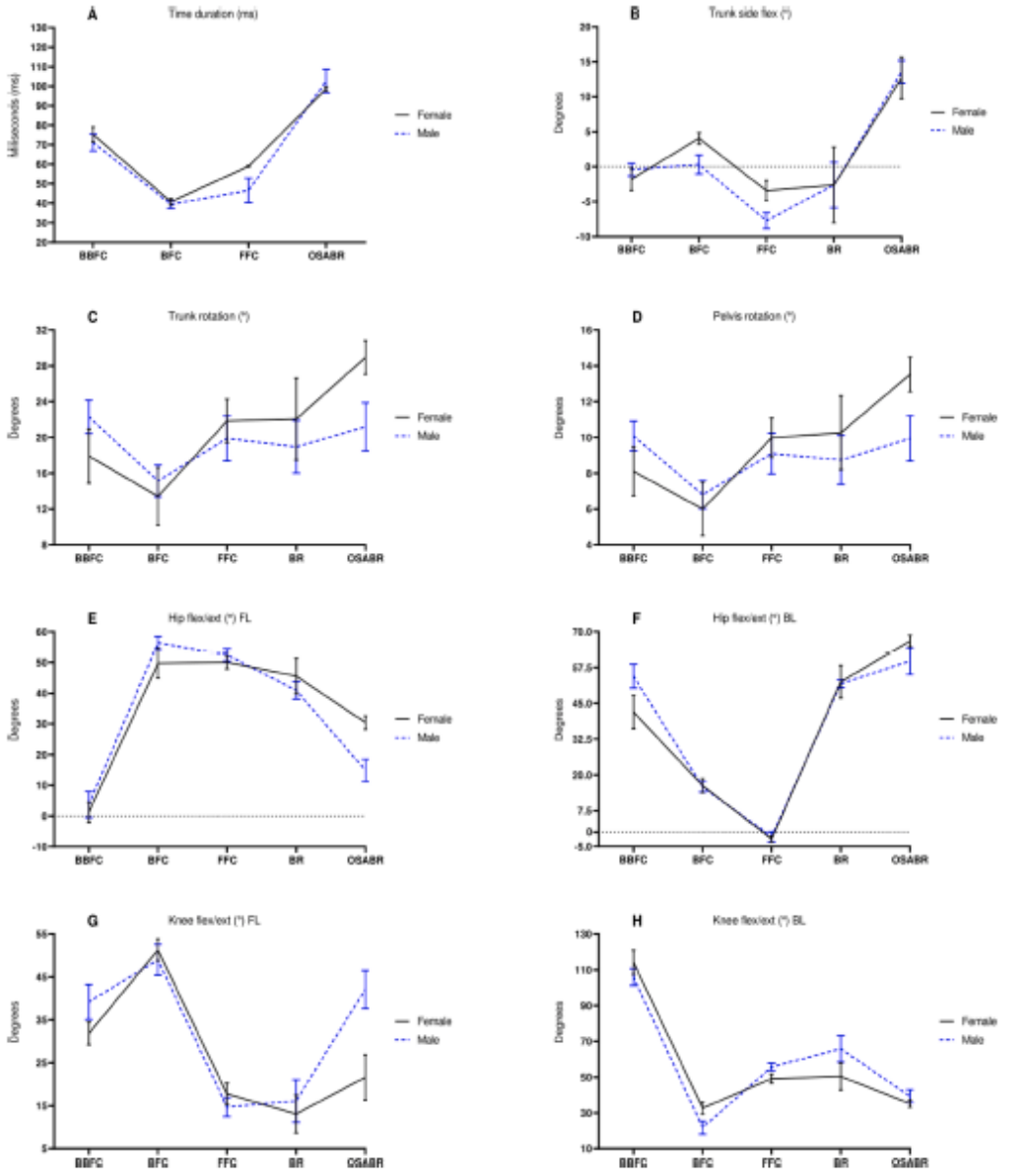


Fig. 2. Line graphs of biomechanical comparisons between elite male and female fast bowlers. *Before back foot contact (BBFC), back foot contact (BFC), front foot contact (FFC), ball release (BR), one step after ball release (OSABR), front leg (FL), back leg (BL), flexion (flex), extension (ext).*

side-flexion to generate momentum during the delivery stride. The rate of lower back injuries among female fast bowlers is lower than that of males (Jacobs et al., 2022). Further research should explore whether the initial right trunk flexion at BFC could be a contributing factor to the reduced occurrence of lower back injuries in females. Lower back injury rates in female fast bowlers are less than for males and future research should investigate if the initial right trunk flexion at BFC could be advantageous and a factor in why females have reduced lower back injuries. Future research should investigate a larger sample size of female fast bowlers to investigate their trunk side-flexion strategy, whether this is an increased ball release speed strategy in females, and the effect on injury risk in fast bowlers.

Females in this study presented with higher shoulder counter-rotation than males. The high degrees of shoulder counter-rotation could aid in the transverse momentum generated during the delivery stride. Felton et al. (2019) suggested that female fast bowlers rotate, using the shoulder, trunk, and pelvis during their bowling stride, similar to a throwing technique. This rotational bowling technique could benefit females by generating more momentum to increase ball release speed, but the high shoulder injury rates in female fast bowlers are a concern (Jacobs et al., 2022). Future research should investigate the trade-off between the high degrees of shoulder counter-rotation for bowling performance and the increased risk of shoulder injury associated with this technique. Coaches and clinicians working with female fast bowlers should focus on strengthening the shoulder muscles for improved performance and injury prevention.

A limitation of this study is the small population of elite female fast bowlers, however, still a big sample compared to the entire population. Future research should investigate a larger cohort of elite female fast bowlers, the relationship between musculoskeletal, anthropometrics and bowling biomechanics, and how these factors could influence ball release speed and injury risks. Our study lacks detailed analysis on bowlers' specific techniques (side-on, front-on, or mixed), which could impact observed biomechanical measures. Future research should address technique variations for a comprehensive interpretation of results.

A strength of this study is the use of IMU, as the players could be exposed to an outdoor pitch and environment, which aided the ecological validity as it was closer to match and training circumstances than testing them in laboratories on a different surface. Also, reporting the before-BFC and one step after BR is a strength of this study, as the fast bowling action should be assessed holistically, not just the phase length from BFC to BR. Future studies should include before-BFC as part of their bowling analyses. This segment predicts the setup of kinematics at the BFC, and the phase length from before-BFC to BFC is an essential technique coaches reinforce in their bowlers during coaching sessions.

5. Conclusion

This study suggests that female fast bowlers have unique anthropometry and bowling biomechanics. Female fast bowlers spend more time in the phase lengths of the delivery stride, specifically from BFC to FFC. Females have increased pelvis and trunk rotation from BFC to FFC and BR to one step after BR and increased total shoulder counter-rotation. A novel finding of this study is that females use a different trunk side-flexion strategy compared to males from before-BFC to FFC. Further, the extended time of the phase length through the delivery stride enables the female bowlers to use muscles working in the transverse plane to generate extra rotational momentum to increase ball release speed. Coaches should be aware of these strategies when altering bowling biomechanics of female fast bowlers. The current extrapolation of coaching strategies adopted from male fast bowling may not be relevant for females.

Ethical statement.

Ethical approval and permission to conduct this study were obtained from Cricket South Africa's Medical Research Committee, the respective cricket unions' managers, and the Human Research Ethics Committee (Medical) of the University of the Witwatersrand (M220447).

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CRediT authorship contribution statement

Jolandi Jacobs: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Benita Olivier:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **Corlia Brandt:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **Nathanael Boulle:** Writing – review & editing, Writing – original draft, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jbiomech.2024.112157.

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APPENDIX D - PRISMA-SCR CHECKLIST

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	42
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	43
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	44-45
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	45
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	N/A
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	46
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	46-48
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	278-282
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	48-50

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	50
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	50-52
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	N/A
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	50-51
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	51-52
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	51-52
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	57
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	51-99
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	51-99
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	51-99
Limitations	20	Discuss the limitations of the scoping review process.	91
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	91

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	N/A

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.

* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.

† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).

‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.

§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).*From:* Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMAScR): Checklist and Explanation. Ann Intern Med. 2018;169:467–473. doi: 10.7326/M18-0850.

APPENDIX E – SEARCH STRATEGY AND SEARCH RESULTS

Terms connected by OR		Terms connected by OR		Terms connected by OR
‘‘Cricket sport’’[MeSH Terms] Cricket[Text Word]	**AND**	‘‘female’’[MeSH Terms] “Female”[Text Word] ‘‘women’’[MeSH Terms] “Women”[Text Word]] “Woman”[Text Word] “lad*”[Text Word]	**NOT**	"Gryllidae"[Mesh Terms] “crickets”[Text Word]

Terms was searched in MeSH terms as well as all text words and ‘‘humans’’[filter] were applied.

Initial search (Step 1) conducted in **MEDLINE via PubMed** on *2023/08/11* to identify keywords

((((("cricket sport"[MeSH Terms] OR "Cricket"[Text Word]) AND ("Female"[MeSH Terms] OR "Female"[Text Word] OR "Women"[MeSH Terms] OR "Women"[Text Word] OR "Woman"[Text Word] OR "lad"[Text Word])) NOT "crickets"[All Fields]) NOT "Gryllidae"[MeSH Terms]) AND (humans[Filter])

Results 179

Searches conducted on 12/09/2023:

MEDLINE® (12/09/2023)

Keywords were searched in all texts (including title/abstract) and MeSH terms.

((((("cricket sport"[MeSH Terms] OR "Cricket"[Text Word]) AND ("Female"[MeSH Terms] OR "Female"[Text Word] OR "Women"[MeSH Terms] OR "Women"[Text Word] OR "Woman"[Text Word] OR "lad"[Text Word])) NOT "Gryllidae"[MeSH Terms]) AND "humans"[MeSH Terms] AND "Female"[MeSH Terms]) AND (female[Filter])

Results: 179

The Cochrane Controlled Trials Register in the Cochrane Library (12/09/2023)

Keywords were searched for in all text words and MeSH terms. Word variations were searched (box ticked). No filters were applied.

ID	Searched for	Results
#1	(women) OR (woman) OR (female*) OR (lady) OR (ladies)	975831
#2	(cricket*)	139
#3	Gryllidae	8
#4	#1 AND #2 NOT #3	38
#5	MeSH descriptor: [Female] explode all trees	582353
#6	MeSH descriptor: [Women] explode all trees	1209
#7	#5 OR #6	582370
#8	MeSH descriptor: [Cricket Sport] explode all trees	7
#9	MeSH descriptor: [Gryllidae] explode all trees	8
#10	#7 AND #8 NOT #9	0
#11	#4 OR #10	38

Results: 38

Physiotherapy Evidence Database (PEDro) (12/09/2023)

The PEDro search builder provides tabs to be selected / filled out in order to conduct the search. The keyword “cricket*” was searched for in ‘Abstract and Title’ and the other keywords were substituted in the tab options. No filters were applied.

Searched for	Results
Cricket*	6
Cricket* AND (female OR woman OR women OR lady OR ladies)	0

Results: 0

EBSCOHost (12/09/2023)

Databases: CINAHL Ultimate, MasterFILE Complete, SPORTDiscus

A combined search was conducted in all the databases affiliated with EBSCOHost: The search was done in all texts; a search in MeSH terms was not available.

The following filters were used during the searches:

Expanders: apply equivalent subjects

Gender: female

Population: female, human

Sources: Academic journals, reviews, reports, dissertations, conference materials

Search TX - All Text:		**Results**
S1	TX cricket OR TX cricket sport	448
S2	TX (female or woman or women or females) OR TX lady OR TX ladies	2083865
S3	Tx gryllidae	463
S4	S1 AND S2 NOT S3	409

Results: 409

SCOPUS (12/09/2023)

Keywords were searched in all text words (including title/abstract). The MeSH terms search was not available. The “human” and “female” filters were applied.

The key string was searched in the advanced search option:

(ALL (cricket*) AND ALL (female* OR women OR woman OR ladies OR lady) AND NOT ALL (crickets) AND NOT ALL (gryllidae)) AND (LIMIT-TO (EXACTKEYWORD , "Human") OR LIMIT-TO (EXACTKEYWORD , "Humans") OR LIMIT-TO (EXACTKEYWORD , "Female"))

Results: 753

Science Direct (12/09/2023)

Keywords were searched in all text words (including title/abstract). The MeSH terms search was not available. The following filters were applied:

Subject areas excluded:

Agricultural and Biological Sciences; Biochemistry, Genetics and Molecular Biology;

Veterinary Science and Veterinary Medicine; Environmental Science, Immunology and Microbiology

Searched for	**Results**
1. cricket AND (female OR females OR woman OR women OR lady OR ladies) NOT gryllidae	4083

Results: 4083

ProQuest Health and Medical Complete (12/09/2023)

Searched in all text:

Set No.	Searched for	Results
S1	(cricket or cricketer or cricketers) OR Cricket OR (cricket sport). Additional limits - Humans; Females	46083
S2	female OR woman OR women OR lady OR ladies Additional limits - Humans; Females	260872
S3	S1 AND S2. Additional limits - Humans; Females	666

Results: 666

APA PsycINFO (12/09/2023)

Searched in all text:

((cricket or cricketer or cricketers) OR Cricket OR (cricket sport)) AND (female OR woman OR women OR lady OR ladies) Additional limits - Humans; Females

Results: 69

WorldCat (12/09/2023)

A full text search option was not available. Searches were done in keywords. The search was refined by: 'Formats': articles: all (ticked); books: thesis/dissertation (ticked), manuscripts (ticked). Other formats such as video, image, music, etc., were excluded.

((kw:female* OR women OR woman OR lady OR ladies) AND (kw:cricket*) NOT (kw:Gryllidae))

Results: 4374

Grey Matters (CADTH) (12/09/2023)

The search builder provides tabs to be selected / filled for a refined search. No applicable filters or limitations applied. The following keywords were searched:

Searched for	Results
Cricket*	0
Cricket* AND (female* OR woman OR women OR lad*) `	0

Results: 0

OpenGrey SIGLE (12/09/2023)

The following search was conducted in all texts: (No filters or limitations were applied)

(cricket* AND (female* OR woman* OR women* OR lady* OR ladies)

Results: 0

ClinicalTrail.gov (12/09/2023)

The advanced search builder was used by entering different keywords in selected tabs:

Condition or disease: -

Other terms: cricket*

Filter applied; sex: studies with female participants

Results: 16

Google Scholar (12/09/2023)

Due to the limitations in the advanced search function of Google Scholar, multiple searches were performed. Different variations were searched for separately in the boxes “with all of the words” and “with the exact phrase” as shown below:

Search terms anywhere in the article:

	Search 1	Search 1	Search 1	Search 1	Search 1
with the exact phrase	Female Cricket	Women cricket	Women’s cricket	Woman cricket	Ladies cricket
Without the words	insect gryllidae	insect gryllidae	insect gryllidae	insect gryllidae	insect gryllidae
Total number of results	766	776	695	33	140

Total search results from Google Scholar: 2410

APPENDIX F – DATA EXTRACTION INSTRUMENT

Authors	
Year of study and year of publication	
Title of study/report	
Origin (country/context)	
Aims/purpose	
Sports science or medicine discipline	
Study population and sample size (female only/ male and female)	
Study setting (level of play)	
Study design	
Study sample	
How homogenous/heterogenous? i.e. to get numbers is the sample more heterogeneous? Or perhaps an 'elite' female team is more heterogeneous than an elite male team as mix of ages, professionalism etc.	
Intervention description	
Outcome measures	
Data analyses (capture if small sample size/poor data quality could affect analyses)	
Main results (conclusive/ inconclusive)	
Study strengths	
Study limitations	
Author's suggestion for future studies/policies	
Practical/clinical application	
Citation details (eg, author/s, date, title, journal, volume, issue, pages)	

APPENDIX G – ETHICAL CLEARANCE CERTIFICATES

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG	HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

09/02/2022

Professor B Olivier, et al
School of Therapeutic Sciences
Departmentof Physiotherapy
Medical School
University

Sent by e-mail to: Benita.Olivier@wits.ac.za

Dear Professor Olivier

Re: **Protocol Ref No:** M170726
Protocol Title: *Injury prevention in cricket fast bowlers: the Fearless Fast Bowling Project*
Principal Investigators: Professor B Olivier, et al

I refer to your letter of 09/02/2022.

I confirm that we have noted and approve of the proposed addition of Ms J Jacobs to the investigative team on this study.

Thank you for keeping us informed.

Yours Sincerely

J. Burns
.....
Mr I Burns
For the Human Research Ethics Committee (Medical)

CB Penny
.....
Dr CB Penny, Chairperson, Human Research Ethics Committee (Medical)

Cricket South Africa (NPC)
86, 5th Street, Melrose Estate, 2196
PO Box 55009, Northlands, 2116
Tel: +27 (0)11 880 2810
Fax: +27 (0)11 880 6578
Website: www.cricket.co.za

9 May 2022

TO WHOM IT MAY CONCERN

RE: PERMISSION TO USE CRICKET SOUTH AFRICA RESOURCES FOR RESEARCH PURPOSES
RESEARCHER: JOLANDI JACOBS

In my capacity as Chief Medical Officer: Cricket South Africa, I grant permission for the study titled "Bowling kinematics and factors associated with injury and performance in women's cricket" to be conducted and to invite female cricket players from the following teams Northerns Senior Women's Cricket Team, the Easterns Senior Women's Cricket Team and Gauteng Senior Women's Cricket Team to participate voluntarily.

DR SHUAIB MANJRA
CHIEF MEDICAL OFFICER

Directors: Mr Lawson Naidoo (Chairman)*, Mr Steven Budlender SC (Lead Independent Director)*, Mr Norman Arendse SC*, Mr Daniel Govender, Mr Andrew Hudson*, Dr Simo Lushaba*, Mr John Mogodi, Mr Craig Nel, Mr Simphiwe Ndzundzu, Mr Andisa Ntsubane*, Mr Mark Rayner*, Ms Muditambi Ravele*, Mr Tebogo Siko, (* denotes Independent)

Acting Chief Executive: Mr Pholetsi Moseki
Acting Chief Financial Officer: Ms Christelle Janse van Rensburg

Cricket South Africa (Non-Profit Company) | Company Registration: 2002/002641/08

APPENDIX H – INFORMATION SHEET AND INFORMED CONSENT FORMS

Physiotherapy

School of Therapeutic Sciences, Faculty of Health Sciences | Private Bag 3, WITS, 2050, South Africa
T +2774 444 8542 | **E** jolandi.jacobs@wits.ac.za | **W** https://www.wits.ac.za/wcrh/

INFORMATION DOCUMENT: Female Cricket Player

Study title: Injury and performance indicators in women's cricket

Dear Female Cricket Player

I, Jolandi Jacobs, am doing research on the injury and performance indicators in women's cricket. Research is just the process used to learn the answer to a question. In this study, we want to learn which cricket technique-related factors relate to injury. We also want to learn which technique-related factors relate to performance. The technique-related factors which are found to be protective against injury and which enhance performance at the same time can be emphasised during cricket coaching. The recording of bowling workload is additionally beneficial, as the interpretation of findings will account for the role of training volume in injury prevention and performance. If female cricketers can be followed up over a season, associations with performance and injury can be established.

I would be most grateful if you would be willing to participate in this research project. The project is scheduled to commence in July 2022 and commence in December 2023.

Who is eligible to take part in this study?
Female cricket players aged 16 years and older can play matches for their domestic cricket team. Players who underwent surgery on the spine and lower limbs are not eligible to take part in this study.

What is involved in the study?
Testing will be done during one of your cricket practice sessions. On the day of testing, you will be asked to complete a questionnaire enquiring about demographic and injury-related information. You will then be given time to warm up in your preferred manner. Testing will be done with your bowling shoes on, your shirt removed (males) or with a strap top on (females), and you will be required to wear ski pants. I have ski pants available should you not have your own. Light reflective markers will be attached to specific sites on your body. Thereafter, you will be required to do physical tests related to cricket injury and performance.

Injury status and training volume will be monitored throughout the cricket season with the aid of an application that you can load onto your cell phone. Should you prefer to record injury status and bowling performance via hard copy, you are welcome to do so. Participation is voluntary and refusal to participate will not involve any penalty or loss of benefits to which you are otherwise entitled. You may withdraw from this study at any time without suffering any repercussions.

Are there any risks of taking part in this study?
You will not be exposed to any additional risks other than the risk that you are normally exposed to when you are playing cricket.

What are the benefits of taking part in this study?
Your performance stats will be measured and given to you. I will not make recommendations to improve your technique, but I will give you feedback on your technique which will allow you to analyse your technique. Non-identifiable, generalised results will be made available to all participants at the end of the study. No monetary award will be given for taking part in this study.

Will access to information be controlled?
When you complete the questionnaires, identifying information will be captured such as name, surname and email address. If you are completing this questionnaire because your school or club has implemented this injury and workload surveillance system, the raw data will be submitted to your school or club's coaching and/or health care team as specified in your agreement with the school or club.

However, for research purposes the primary investigator, Benita Olivier and her research team which includes students, will have access to the raw data and at the time that data will be exported for research analysis. No information such as name, surname or contact details, will be exported and all participants will be allocated study numbers. You can request for your responses to be withdrawn from this research study by emailing the primary investigator, Benita Olivier (see email address below), on or before the last day of the last match of the cricket season in which you completed the questionnaire(s) without suffering any repercussions.

Information related to the use of your data in future research projects:
We would like to get your permission to deposit your data into a research database that will be used for future research by bona fide researchers. At the moment, we do not know what the future research questions are, but if there is any specific topic that you would prefer

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Private Bag 3, WITS, 2050, South Africa | **T** +2774 444 8542 | **E** jolandi.jacobs@wits.ac.za
W https://www.wits.ac.za/wcrh/

your data not to be used for, then you can specify this in the consent form. Your data will not be sold for profit and you can indicate in the consent form if you prefer for your data not to be used in commercial projects (e.g. device development).

Will access to my data be controlled?
Identifying information, such as your name, surname, and contact details, will be removed from your data and a study number will be allocated to your data. The link between the study number and the identifying information will be kept in an access-controlled database which is only accessible by the data manager, access control committee and research group director. If you would like to review the accuracy of your data, feel free to contact the data manager (via Benita Olivier, email address below) who will set up a meeting for you to verify information.

Where will my data be stored?
Your data will be stored on a secure platform called REDCap (Research Electronic Data Capture) which is hosted by the University of the Witwatersrand. This platform is access-controlled, secured on two different servers and only a data manager, data access committee and the research group director will have access to the data.

How will researchers gain access to my data?
Researchers who would like to use your data in future research projects will apply for ethical clearance. In addition, these applications will be reviewed by a data access control committee in the light of the intension of your original consent. If the committee is satisfied with the intentions of use, access will be granted to your data. Your data might be linked to other datasets and merged with multiple sources of data. Upon completion of the project, the researcher will be required to upload the modified datasheet onto the REDCap system and remove the copies from his/her computer, whereafter the researcher's access to REDCap will be terminated.

Should you prefer not to allow for your data to be used in either the current or future research projects, or both, you will not lose out on any benefits that you are entitled to in the absence of this research project. If you would like to withdraw your consent for re-use of your data in future research projects you are free to do so by sending an email to the primary investigator, Benita Olivier (see email address below).

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Will information be handled as confidential?
Efforts will be made to keep personal information confidential. Absolute confidentiality cannot be guaranteed. Personal information may be disclosed if required by law. To ensure the confidentiality of participants, each bowler will be assigned a study number. The key to the study numbers assigned will be kept by the researcher only. Names of participants are only to be written on the consent form and not on the questionnaire. Additionally, consent forms are to be kept separately from the questionnaires. All information will be used only for the purpose intended in this study only.

For further information, you are welcome to contact me on 0744448542 or send an email to jolandi.jacobs@wits.ac.za.

For more information on, or for the reporting of ethical concerns, you may contact the chair of the Human Research Ethics Committee of the University of the Witwatersrand:
Prof Cleaton Jones; Tel: 011-717-2700

Kind regards,

Jolandi Jacobs
Physiotherapy Department
University of the Witwatersrand

INFORMED CONSENT FORM: FEMALE CRICKET PLAYER

Study title: Injury and performance indicators in women's cricket

I_____(e-mail address: _____ and cell phone number:_____) hereby agree to for my data to be used as stipulated below:.

I agree for my data to be used as part of the research project described in the information sheet and titled: "Injury and performance indicators in women's cricket project".
☐ Yes
☐ No

I am aware that I can request for my data to be withdrawn from this particular research study, on or before the last day of the last match of the cricket season in which I completed the questionnaire(s), without suffering any repercussions.
☐ Yes
☐ No

I understand that there are no monetary rewards for allowing my data to be used as part of this research study and that participation is voluntary and I am not in any way obliged to take part.
☐ Yes
☐ No

I agree for my data, after my name, surname and contact details have been removed, be re-used in future research projects without my additional informed consent (tick all that apply).

☐ Yes, my data can be stored and re-used for an unlimited period of time.

☐ Yes, my data can be stored and re-used for a limited period of time with an end date specified here: _____(DD/MM/YYYY).

☐ Yes, my data can be re-used as part of a project of any type which has been approved by the data access control committee except for topics such as: _____(leave blank if not applicable).

☐ Yes, my data can be used in commercial or device development projects.

☐ No, I do not agree for my data to be used in future research projects.

Signature of bowler _____ Date: _____

Signature of researcher _____

For office use only:
Study number:_____

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INFORMED CONSENT FORM: GUARDIAN/PARENTS OF FEMALE CRICKET PLAYERS

Study title: Injury and performance indicators in women's cricket

I_____(e-mail address: _____ and cell phone number:_____) hereby agree to for my child's data to be used as stipulated below:.

I agree for my child's data to be used as part of the research project described in the information sheet and titled: "Injury and performance indicators in women's cricket project".
☐ Yes
☐ No

I am aware that I can request for my child's data to be withdrawn from this particular research study, on or before the last day of the last match of the cricket season in which I completed the questionnaire(s), without suffering any repercussions.
☐ Yes
☐ No

I understand that there are no monetary rewards for allowing my child's data to be used as part of this research study and that participation is voluntary and I am not in any way obliged to take part.
☐ Yes
☐ No

I agree for my child's data, after his/her name, surname and contact details have been removed, be re-used in future research projects without my additional informed consent (tick all that apply).

☐ Yes, my child's data can be stored and re-used for an unlimited period of time.

☐ Yes, my child's data can be stored and re-used for a limited period of time with an end date specified here: _____(DD/MM/YYYY).

☐ Yes, my child's data can be re-used as part of a project of any type which has been approved by the data access control committee except for topics such as: _____(leave blank if not applicable).

☐ Yes, my child's data can be used in commercial projects (e.g. device development).

☐ No, I do not agree for my data to be used in future research projects.

Signature of parent/guardian _____ Date: _____

Signature of researcher _____

For office use only:
Study number:_____

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APPENDIX I – INJURY SURVEILLANCE QUESTIONNAIRE

Confidential

Injury Surveillance Questionnaire

Please complete the survey below.

Thank you!

Injury information	
Have you suffered from an injury in the last month? (if you can't clearly remember whether you reported an injury yet or not, just report it anyway)	◯ Yes ◯ No (Injury definition: any neuromusculoskeletal condition which affects your ability to perform during a match or training; this includes any chronic condition which you started the season with, or developed during the season.)

If you have not sustained an injury this month then no further information is needed.

In your opinion, has a change in your bowling/training workload/intensity played a role in the development of your injury/pain?	◯ Yes, an increased workload/intensity ◯ Yes, a decreased workload/intensity ◯ No
Please tick the areas injured in the last month.	☐ Head or face ☐ Neck ☐ Shoulder ☐ Upper arm ☐ Elbow ☐ Forearm ☐ Wrist ☐ Hand/finger ☐ Chest injury ☐ Trunk and abdominal ☐ Thoracic spine ☐ low back ☐ Pelvis/buttocks (excluding groin) ☐ Hip and groin ☐ Thigh (hamstring) ☐ Thigh (quadriceps) ☐ Knee ☐ Lower leg ☐ Ankle ☐ Foot ☐ Injury site unspecific or crossing anatomical boundaries ☐ Others, please specify

Please indicate what the nature of the injuries you sustained

	Joint Sprain	Joint dislocation	Muscle injury	Fracture	Nerve injury	Cut or graze	Organ injury	Other
Head or face injury	○	○	○	○	○	○	○	○
Neck injury	○	○	○	○	○	○	○	○
Shoulder injury	○	○	○	○	○	○	○	○
Upper arm injury	○	○	○	○	○	○	○	○
Elbow injury	○	○	○	○	○	○	○	○
Forearm injury	○	○	○	○	○	○	○	○
Wrist injury	○	○	○	○	○	○	○	○
Hand/finger injury	○	○	○	○	○	○	○	○
Chest injury	○	○	○	○	○	○	○	○
Trunk injury	○	○	○	○	○	○	○	○
Abdominal injury	○	○	○	○	○	○	○	○
Thoracic spine injury	○	○	○	○	○	○	○	○
Low back injury	○	○	○	○	○	○	○	○
Pelvis/buttock (excl groin) injury	○	○	○	○	○	○	○	○
Hip/groin injury	○	○	○	○	○	○	○	○
Hamstring injury	○	○	○	○	○	○	○	○
Quadriceps injury	○	○	○	○	○	○	○	○
Knee injury	○	○	○	○	○	○	○	○
Lower leg injury	○	○	○	○	○	○	○	○
Ankle injury	○	○	○	○	○	○	○	○
Foot injury	○	○	○	○	○	○	○	○
Injury site unspecific or crossing anatomical boundaries	○	○	○	○	○	○	○	○
Other	○	○	○	○	○	○	○	○

You chose "injury site unspecific or crossing anatomical boundaries", please specify _____

You chose "other" injury, please specify _____

You chose "other" as the nature of your head or face injury, please specify _____

You chose "other" in describing the nature of your neck injury, please specify _____

You chose "other" in describing the nature of your shoulder injury, please specify _____

You chose "other" in describing the nature of your upper arm injury, please specify _____

You chose "other" in describing the nature of your elbow injury, please specify _____

You chose "other" in describing the nature of your forearm injury, please specify	_____
You chose "other" in describing the nature of your wrist injury, please specify	_____
You chose "other" in describing the nature of your hand injury, please specify	_____
You chose "other" in describing the nature of your chest injury, please specify	_____
You chose "other" in describing the nature of your trunk injury, please specify	_____
You chose "other" in describing the nature of your abdominal injury, please specify	_____
You chose "other" in describing the nature of your thoracic injury, please specify	_____
You chose "other" in describing the nature of your low back injury, please specify	_____
You chose "other" in describing the nature of your pelvis/buttock (excl groin) injury, please specify	_____
You chose "other" in describing the nature of your hip/groin injury, please specify	_____
You chose "other" in describing the nature of your hamstring injury, please specify	_____
You chose "other" in describing the nature of your quadriceps injury, please specify	_____
You chose "other" in describing the nature of your knee injury, please specify	_____
You chose "other" in describing the nature of your lower leg injury, please specify	_____
You chose "other" in describing the nature of your ankle injury, please specify	_____
You chose "other" in describing the nature of your foot injury, please specify	_____
You chose "other" in describing the nature of your injury which is unspecific or crossing anatomical boundaries, please specify	_____
You chose "other" in describing the nature of your other injury, please specify	_____

Please answer the following relating to your head or face injury	
Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the initial injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014
Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____
Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other

During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your neck injury

Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the initial injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014
Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____

Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other
During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your shoulder injury

Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the initial injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014

Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____
Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other
During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your upper arm injury	
Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014
Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____
Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other

During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your elbow injury

Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014
Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____

Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other
During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your forearm injury

Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade). A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered.)
Please indicate the season in which the injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014

Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____
Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other
During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your wrist injury	
Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014
Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____
Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other

During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your hand_finger injury

Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014
Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____

Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other
During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your chest injury

Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014

Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____
Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other
During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your trunk injury	
Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014
Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____
Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other

During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your abdominal injury

Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014
Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____

Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other
During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your thoracic injury

Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014

Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____
Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other
During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your low back injury	
Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014
Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____
Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other

During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your pelvis_buttock injury

Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014
Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____

Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other
During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your hip_groin injury

Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014

Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____
Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other
During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your hamstring injury	
Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014
Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____
Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other

During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your quadriceps injury

Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014
Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____

Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other
During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your knee injury

Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014

Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____
Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other
During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your lower leg injury	
Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014
Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____
Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other

During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your ankle injury

Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014
Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____

Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other
During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your foot injury

Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014

Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____
Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other
During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your injury which is unspecific or crossing anatomical boundaries	
Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014
Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____
Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other

During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

Please answer the following relating to your other injury

Select the side of the body where the injury occurred	◯ Left ◯ Right ◯ Both sides
Have you previously suffered the same injury? Or is this a chronic injury?	◯ Yes, recurrent ◯ No, no first time ◯ Chronic (A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered. An injury is considered recovered once a player has returned to full (unrestricted) participation in at least one match (of any type or grade).)
Please indicate the season in which the injury occurred	☐ 2016 off season ☐ 2015/2016 season ☐ 2015 off season ☐ 2014-2015 ☐ Prior to 2014
Would you describe this injury as a contact injury or as a non-contact injury?	◯ Contact injury ◯ Non-contact injury (A contact injury is when you get injured when colliding with the ground, a ball or another player)
Would you describe this/the initial injury as acute or as gradual onset?	◯ Acute ◯ Gradual onset
Date of injury	_____
Approximate duration of symptoms (weeks)	_____

Please select whether the initial injury occurred during a training session or match	◯ Practice ◯ Match ◯ Other
You chose "other" - please specify	_____
Please briefly state how the injury occurred	_____
During which activity did the injury occur?	◯ Bowling ◯ Batting ◯ Fielding ◯ Other
During which match environment did the injury occur?	◯ T20 ◯ 60 Over ◯ 50 Over ◯ 45 Over ◯ Other
Did this injury 1) prevented the player from being fully available for selection for a match or 2) during a match, caused the player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain?	◯ Yes ◯ No
Was surgery required for this injury?	◯ Yes ◯ No

APPENDIX J – STROBE-SIIS: CHECKLIST OF ITEMS FOR THE REPORTING OF OBSERVATIONAL STUDIES ON INJURY AND ILLNESS IN SPORTS

Item No	Item	Response
1.1	Study design in the title	The title includes study design: injury profiles in sub-elite women's cricket
1.2	Include sport, population, duration and level in abstract	Included in the abstract: sub-elite women's cricket over one season
2	Scientific background and rationale	Included in introduction
3	State specific objectives	Included in the introduction: describe the injury epidemiology in women's cricket
3.1	State whether study was registered	The study was not registered
3.2	State the specific purpose of your study	The purpose of the study stated in the introduction
4.	Study design	Prospective cohort study
4.1	Clearly state which health problems are being observed	Health problems stated in the introduction
4.2	Outcome measure/tool	All injury definitions and calculations according to the updated Cricket Consensus Statement
4.3	Coding system	All injury definitions and calculations according to the updated Cricket Consensus Statement and Orchard Sports Injury and Illness Classification System (OSIICS) version 13
4.4	Clearly describe how athletes were categorised	All injury definitions and calculations according to the updated Cricket Consensus Statement
5.1	Location, level of play, dates of observation and data collection methods	Injury epidemiology of sub-elite South African female cricket players over a season
5.2	Dates of the surveillance period	One season (six months)
5.3	Data collection method	Prospective data collection
6.1	Selection of cohort	Three teams participating in the CSA's domestic women's cricket league were included in this study
7.1	Outcomes	Describe injury profiles in sub-elite women's cricket
7.2	Secondary outcomes	Exploring incidence, prevalence, nature, onset, activity and body region injured in sub-elite women's cricket

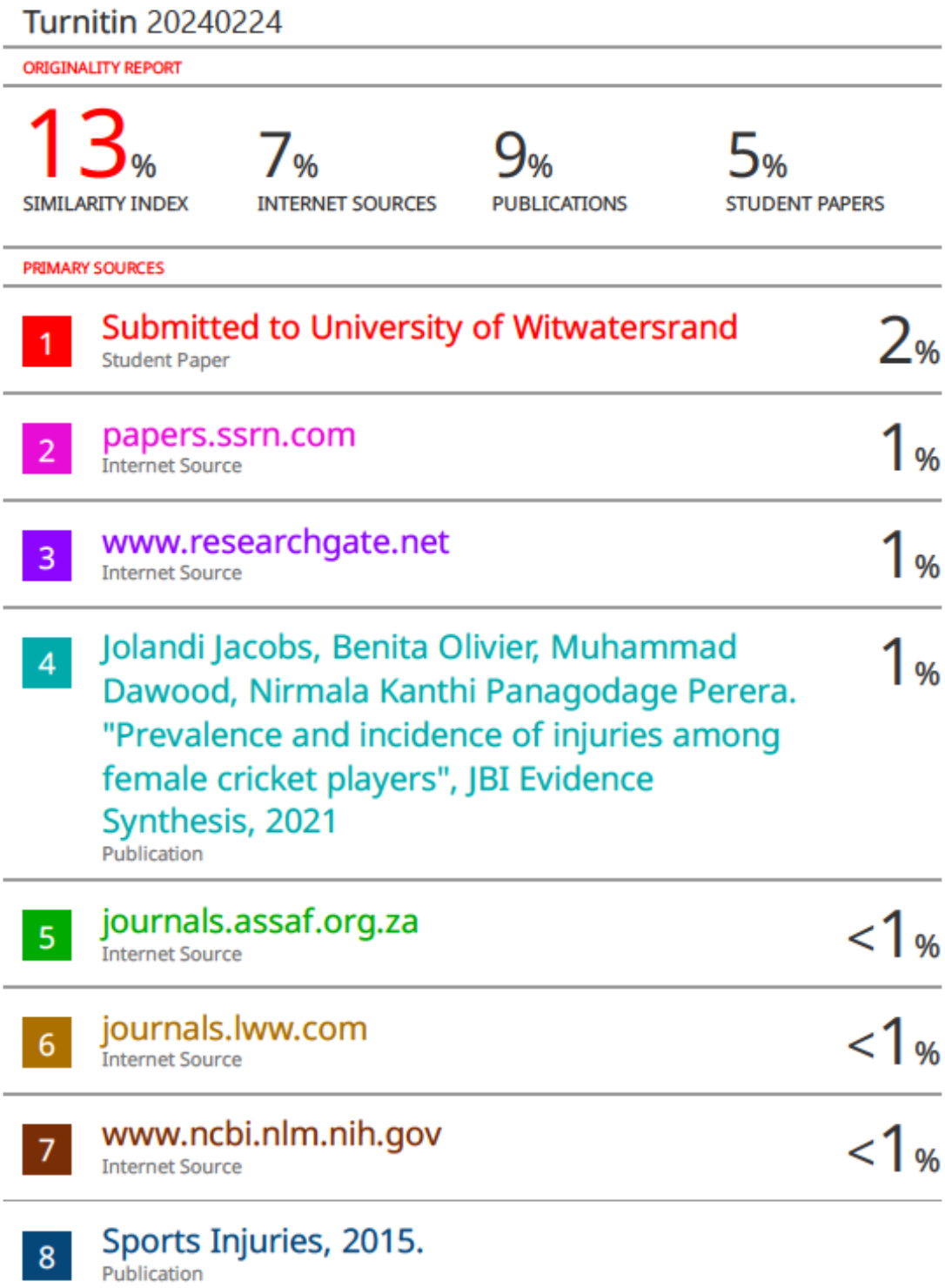
Item No	Item	Response
8.1	Who collected/reported the data	Addressed and explained in detail in the methods section
8.2	Who coded the data	
8.3	Data collection methods	
8.4	Timing window for data collection	
8.5	Duration of surveillance	
9.1	validation or reliability assessment of the data collection of tools	Addressed and explained in detail in the methods section
9.2	Formally acknowledge any potential biases in associated with the data collection method	
10	Explain how study size was calculated	This is a limitation of this study and is listed in the discussion section
11	Explain how quantitative variables were handled in the analyses	Explained in detail in the methods section
12.1	Specify how exposure to risk has been adjusted for and specify the units	Included in results and extra calculations in the supplementary document
12.2	Specify calculations	Explained in text and calculations in the methods section
12.3	Exposure to risk adjustments	Explained in text in the methods section
12.4	For studies reporting multiple health problems, state clearly how these were handled	Followed guidelines as per the updated Cricket Consensus Statement as explained in text in the methods section
12.5	Outline how the loss to follow-up is managed	All players were followed up till the completion of the injury surveillance study
13.1	Clearly state the number of athletes followed-up	44 players were monitored over the season
13.2	For studies over multiple seasons/years, report the total numbers of health problems	N/A, as this study occurred over one season
13.3	Give reasons for non-participation at each stage	N/A, all players included for analysis
14	Descriptive data	Age levels, skill levels and sex listed
15	Outcome data	Incidences and prevalence were calculated according to the updated Cricket Consensus Statement, reflecting an

Item No	Item	Response
		accurate calculation of incidences (one or more injuries) vs injuries per squad (prevalence %)
16.1	Report exposure-adjusted incidence or prevalence measures	N/A as adjusted measures were not performed
16.2	Report details of interest, such as mode of onset	All details of interest reported in the results section
17	Other analyses	Tables and figures in the article and supplementary document present all data analysis
18	Key results	Key results presented in the discussion and listed in a supplementary document
19	Limitations	Limitations listed in the discussion
20	Interpretation	Interpretation of data is discussed
21	Generalisability	Data from this study can be generalised to the sub-elite women's cricket population and addresses a critical gap in the literature
22	Funding	Source of funding listed
23	Ethics	All ethical considerations explained in the methodology

APPENDIX K – ANTHROPOMETRIC VARIABLES FOR BOWLING ANALYSES STUDY

Variable	Measurement
Total height (mm)	Highest point on the head to floor (barefoot)
Shoulder height (mm)	C7 spinous process to floor (barefoot)
Shoulder width (mm)	Left to right acromion
Arms spam (mm)	Distal middle finger left to distal middle finger right
Hip height (mm)	Greater trochanter to floor (barefoot)
Hip width (mm)	ASIS to ASIS
Knee height (mm)	Lateral epicondyle to floor (barefoot)
Ankle height (mm)	Medial malleolus to floor (barefoot)
Shoe height (mm)	Shoes on, inner sole width (in line with medial malleolus)
Foot length (mm)	Shoes on, posterior heel to distal big toe

APPENDIX L – TURNITIN REPORT



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