An Investigation Of Sex-Specific Considerations Relating To Physical Preparation In Women's Rugby Union.

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Thesis Submitted for the Award of PhD

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Declaration:

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Doctor of Philosophy is entirely my own work, and that I have exercised reasonable care to ensure that the work is original, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

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Date: 05/01/2024

ID No: 19213611

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To Ischa Lynch, my future wife. For all your love, sacrifice and support I will be forever grateful. You have always believed in, and encouraged me to pursue my goals. All this would not have been possible without you. Thank you.

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Original research article

Lees MJ, **Nolan D**, Amigo-Benavent M, Raleigh CJ, Khatib N, Harnedy-Rothwell P, FitzGerald RJ, Egan B, Carson BP. (2021). A Fish-Derived Protein Hydrolysate Induces Postprandial Aminoacidaemia and Skeletal Muscle Anabolism in an In Vitro Cell Model Using Ex Vivo Human Serum. Nutrients. 13(2):647.

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Nolan, D., Lynch A., Egan B. (2022). Self-Reported Prevalence, Magnitude, and Methods of Rapid Weight Loss in Male and Female Competitive Powerlifters. Journal of Strength and Conditioning Research 36(2), 405-410.

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Table of Contents:

Declaration: i
Acknowledgments: ii
Peer-reviewed Publications Arising from this Thesis: iii
Conference Presentations Arising from this Thesis: iv
Additional Peer-reviewed Publications Independent of this Thesis: v
DCU Graduate Training Elements Completed During Course of PhD: vi
List of Figures: xi
List of Tables: xii
List of Abbreviations: xiii
Abstract xiv
Chapter 1 – 1
Introduction & Literature Review 1
- Introduction To Women's Rugby Union, Athletic Development and Between-sex Differences 2
- Positionality: My Professional Experience and Practice 4
- Women's Rugby Union – Current Landscape of Literature 7
  - Physical Performance Characteristics and Training-Induced Adaptation 7
  - Physical Match Characteristics 9
- The Influence of Between-Sex Differences and The Gendered Sport Environment on Athletic Development 11
- The Menstrual Cycle and Hormonal Contraceptives 15
  - Overview of Menstrual Cycle Physiology 16
  - The Menstrual Cycle and Exercise Performance 18
  - Overview of Hormonal Contraceptives 19
  - Hormonal Contraceptives and Exercise Adaptations 20
- Coaching Practices, Athlete Buy-In and Interpersonal Relationships 21
- Thesis Aims 28

Chapter 2 – Study 1 29
'There's a perfect way to do things, and there's a real way to do things': Attitudes, beliefs and practices of strength and conditioning coaches in elite international rugby union. 29
- Abstract 30
- Introduction 32
- Research Philosophy, Design, and Methods 33
  - Research Philosophy and Study Design 33
  - Participants 34

Procedures 35
Data Analysis 36
Trustworthiness 37
Reflexivity & Positionality 37
Results & Discussion 38
Developmental Stage of Women's Rugby 39
Physical Preparation 44
Education 51
Study Strengths and Limitations 53
Conclusions 53
Chapter 3 – Study 2 58
'Male Athletes Play Well to Feel Good, and Female Athletes Feel Good to Play Well': Attitudes, Beliefs, and Practices Pertaining to Communication and Interpersonal Approach of Strength and Conditioning Coaches in International Women's Rugby Union. 58
Abstract 59
Introduction 60
Research Philosophy, Design, and Methods 61
Results and Discussion 62
Athlete Engagement 62
Interpersonal Approach 66
Study Strengths and Limitations 70
Conclusions 71
Chapter 4 – Study 3 74
Abstract 75
Introduction 77
Methods 78
Experimental approach to the problem 78
Subjects 79
Data analysis 79
Results 80
Subjects and prevalence of HC use 80
Menstrual cycle (non-HC users) 83
HC Use 85
Discussion 86
Chapter 5 – Study 4 91
Abstract: 92

Introduction 93
Materials and Methods 94
Results 96
Discussion 98
Conclusions 101
Chapter 6 – Study 5 103
Abstract 104
Introduction 106
Methods 107
Literature Search and Management 107
Study Selection 109
Data Extraction, Moderators, and Study Quality 110
Calculation of Effect Sizes 111
Statistical Analysis 111
Results 112
Differences in Untrained Participants Prior to Engaging in Resistance Exercise Training 117
Differences in Response to Resistance Exercise Training 121
Sensitivity, Publication Bias and Moderator Analysis 125
Discussion 125
Conclusion: 131
Chapter 7 – Study 6 133
The effect of hormonal contraceptive use on skeletal muscle hypertrophy, power, and strength adaptations to resistance exercise training: a systematic review and multilevel meta-analysis. 133
Abstract 134
Introduction 136
Methods 137
Literature Search and Management 137
Study Selection 139
Data Extraction, Moderators, and Study Quality 139
Calculation of Effect Sizes 141
Statistical Analysis 141
Results 143
Hypertrophy Outcomes 154
Power Outcomes 155
Strength Outcomes 156
Discussion 158

Conclusion 161
Chapter 8 – Main Findings & Conclusion 162
Main Findings 163
Study 1 163
Study 2 164
Study 3 165
Study 4 165
Study 5 166
Study 6 166
Current Research and Future Directions 167
Attitudes Beliefs and Practices of Elite Level Strength and Conditioning Coaches Towards Physical Preparation in Women's Rugby Union 167
The Menstrual Cycle 169
Hormonal Contraceptives 173
Between-sex Differences in Hypertrophy and Strength Adaptations to Resistance Exercise Training 174
Limitations 175
Emerging Issues and Future Directions for Research in Physical Preparation for Female Athletes and Women's Rugby Union 177
Concluding Remarks 179
References 179
Appendices 205
Appendix A: Published article in the International Journal of Sports Science and Coaching 206
Appendix B: Published article in The Physician and Sportsmedicine 223
Appendix C: Published article in the Journal of Functional Morphology and Kinesiology 231
Appendix D: Published Article in Sports Medicine 240
Appendix E: Ethical approval forms 286
Appendix F: Interview guide used in thematic analysis studies 291
Appendix G: Survey – Period Prevalence and Perceived Side Effects of Hormonal Contraceptive Use and the Menstrual Cycle in Athletes 295

List of Figures:

Figure 1. Overview of the Physiology of the Menstrual Cycle. Adapted from Gutierrez-Castellanos et al., 2022 16
Figure 2. Schematic representation of central organizing, higher order, and subthemes 39
Figure 3. Schematic representation of central, higher-order and subthemes. 62
Figure 4. The prevalence of hormonal contraceptive (HC) use and perceived negative side-effects of the menstrual cycle and HC use. IUD, intrauterine device. 82
Figure 5. PRISMA flow diagram. Detailed flow of studies examined from the initial search to the final inclusion 108
Figure 6. Forest plot of fat-free mass raw differences in untrained participants 118
Figure 7. Forest plot of standardised mean differences in upper body strength of untrained participants. 119
Figure 8. Forest plot of standardised mean differences in lower body strength of untrained participants. 120
Figure 9. Forest plot of between-group differences in hypertrophy outcomes for males and females in response to resistance exercise training. Effects >0 indicate a larger magnitude of effect for males. 121
Figure 10. Forest plot of between-group differences in upper body strength outcomes for males and females in response to resistance exercise training. Effects >0 indicate a larger magnitude of effect size for males. 123
Figure 11. Forest plot of between-group differences in lower body strength outcomes for males and females in response to resistance exercise training. Effects >0 indicate a larger magnitude of effect size for males. 124
Figure 12. PRISMA flow diagram. Detailed flow of studies examined from the initial search to the final inclusion 138
Figure 13. Forest plot of hypertrophy outcomes 155
Figure 14. Forest Plot of Power Outcomes 156
Figure 15. Forest plot of strength outcomes 157

List of Tables:

Table 1. Descriptive Characteristics of Participants 35
Table 2. Subject Characteristics............ 81
Table 3. Frequency analysis of side effects in non-hormonal contraceptive users (n=139) 83
Table 4. Frequency Analysis of Side Effects in Hormonal Contraceptive Users (n=145) 85
Table 5. Physical match demands of match play for a squad of international female rugby union players during three consecutive years of the Women's Six Nations Championship............ 96
Table 6. Positional differences in the absolute physical match demands of match play for a squad of international female rugby union players during three consecutive years of the Women's Six Nations Championship. 96
Table 7. Positional differences with pairwise comparisons in the relative physical match demands of match play for a squad of international female rugby union players during three consecutive years of the Women's Six Nations Championship. 97
Table 8. Descriptive Information on Studies Meeting Inclusion Criteria 113
Table 9. Study Characteristics 144
Table 10. Sensitivity Analysis 151
Table 11. OCP Types and Menstrual Status Descriptions 153

List of Abbreviations:

1-repetition maximum	1RM
Second row	2R
Anterior Cruciate Ligament	ACL
Back three	B3
Body mass index	BMI
Back row	BR
Centre	C
Confidence interval	CI
Continual professional development	CPD
Cross sectional area	CSA
Coefficient of variation	CV
Deoxyribonucleic acid	DNA
Dual energy X-ray absorptiometry	DXA
Effect size	ES
Fly half	FH
Front row	FR
Global positioning system	GPS
Hormonal contraceptive	HC
Inter-class correlation	ICC
Intra-uterine device	IUD
Magnetic resonance imaging	MRI
Maximal voluntary isometric contraction	MVIC
National collegiate athletics association	NCAA
Not reported	NR
Oral contraceptive	OC
Oral contraceptive pill	OCP
Open science framework	OSF
Preferred Reporting Items for Systematic review and Meta-Analysis Protocols	PRISMA-P
Relative energy deficiency syndrome	RED-S
Resistance exercise training	RET
Repetition max	RM
Standard deviation	SD
Standard error	SE
Scrum half	SH
Standardised mean difference	SMD
Statistical packages for the social sciences	SPSS
Tool for the assessment of study quality and reporting in exercise	TESTEX

David Nolan

An investigation of sex-specific considerations relating to physical preparation in women's rugby union.

Abstract

Women's rugby union is a team field sport consisting of intermittent bouts of high-intensity efforts. Appropriate physical preparation is an integral element of long-term athletic development. There are well-established sexual dimorphism in anatomical, physiological, psychological and performance factors between sexes, which may have implications for physical preparation.

Study 1 investigated the attitudes, beliefs and practices of strength and conditioning coaches in elite international women's rugby union towards the technical aspects of physical preparation in female athletes. Coaches adopted an androcentric view of physical preparation and do not greatly alter the technical aspects of their approach when training female athletes (Nolan, Horgan, *et al.*, 2023).

Study 2 investigated the attitudes and practices of strength and conditioning coaches in elite international women's rugby union towards interpersonal aspects of coaching female athletes. We found that coaches altered communication strategies when engaging with female athletes and reported a heightened awareness of professional boundaries.

Study 3 investigated the prevalence of hormonal contraceptive use and side effects of the menstrual cycle and hormonal contraceptive use in powerlifters and rugby players (Nolan, Elliott-Sale and Egan, 2023). A large proportion of hormonal contraceptive users and nonusers experienced negative side effects of hormonal contraceptive use and the menstrual cycle, respectively.

Study 4 investigated the physical match demands of elite international women's rugby union match play (Nolan, Curran, *et al.*, 2023). Total running demands were found to be similar to those previously reported in other international cohorts employing similar methodology.

Study 5 was a systematic review and meta-analysis examining baseline sex differences in skeletal muscle hypertrophy and strength outcomes in untrained individuals and subsequent adaptations in response to matched resistance exercise training. Significant differences between males and females were reported in baseline fat free mass and strength in untrained individuals Males and females adapted to resistance training similarly for hypertrophy and lower-body strength, with females displaying a effect for relative upper-body strength.

Study 6 was a systematic review and multilevel meta-analysis, examining the influence of hormonal contraceptive use on skeletal muscle hypertrophy, power and strength outcomes in response to resistance training. Oral contraceptive users and non-users adapted to resistance training similarly, with no significant differences between groups.

Future research should investigate unique factors that may influence physical preparation strategies for female rugby union players which considers the lived experiences of athletes and the impact of systemic and social structures on long-term athlete development.

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Nolan, D., Curran, O., Brady, A.J., and Egan, B. (2023) 'Physical Match Demands of International Women's Rugby Union: A Three-Year Longitudinal Analysis of a Team Competing in The Women's Six Nations Championship', Journal of Functional Morphology and Kinesiology, 8(1), 32, available: https://doi.org/10.3390/jfmk8010032.

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Chapter 1 –

Introduction & Literature Review

Introduction To Women's Rugby Union, Athletic Development and Between-sex Differences

Rugby union can be characterised as an invasion-based team field-sport, featuring intermittent episodes of high-intensity exertions such as running, sprinting, tackling, rucking, mauling, and scrummaging) interspersed with intervals of lower-intensity activity, such as walking, jogging, and resting (Coughlan *et al.*, 2011). In recent years, women's rugby union has witnessed substantial expansion in participation, with approximately 1 million active players registered globally in 2021 ('Women's Survey: Who's Playing the Game?', 2018). Despite this surge and the professionalisation of their male counterparts that commenced nearly three decades ago, the majority of "elite" (international level) female players in the contemporary era have competed in an amateur capacity.

Appropriate "physical preparation", a term synonymous and used interchangeably in this thesis with the terms "strength and conditioning" and "athletic development", is integral to increasing performance capacity and long-term athlete development (Ford *et al.*, 2011; Lloyd *et al.*, 2015a). The professionalisation of the male code and resultant support structures relating to athletic development have, at least in part, contributed to the significantly improved anthropometric and performance characteristics observed each subsequent season over the past two decades (1998-2018), with players becoming on average becoming increasingly bigger (+0.51 kg body mass, +0.90 kg fat-free mass), leaner (-0.41% fat mass), faster (+0.06 m/s maximum speed), more powerful (+12.1 kg/m/s momentum), and covering more distance per game (+11.4 m) each season (Bevan *et al.*, 2022). In recent years (2015-2019), changes in anthropometrics (i.e., decreased skinfolds and increased body mass) and physical performance characteristics (i.e., increased leg strength, upper body strength and momentum) have also been observed in a top two ranked professional international women's rugby union team (Woodhouse, Tallent, *et al.*, 2022), suggesting similar trends may occur in the female game as observed in their male counterparts. Resistance exercise training may be defined as a specialised methodology of physical training in which an individual performs actions against resistive loads with the intention of enhancing health, fitness, and performance (Pichardo *et al.*, 2018). Resistance exercise training is viewed as a fundamental tenet of and widely used by athletic populations in a comprehensive athletic development training program (Schoenfeld *et al.*, 2021). Resistance exercise training typically involves short-duration activities at high, severe, or maximal exercise intensities, encompassing high-force contractions executed in single or relatively few repetitions, usually implemented when increasing maximal strength is the primary objective , which is normally measured through 1-repetition maximum (1RM) testing, that is, the maximal load one can lift / muscular force one can produce in a single repetition of a given movement, for example, the back squat or elbow-flexion. It may also involve contractions of somewhat lower intensity (a submaximal percentage of 1RM), but performed in greater numbers, typically employed when increasing skeletal muscle hypertrophy is a primary aim (Suchomel *et al.*, 2018). Similar hypertrophic adaptations when using either high (≥80% 1RM) or low (≤60% 1RM) loads when proximity to muscular failure is matched between groups, however favourable strength adaptations occur following high-load resistance exercise training (Refalo *et al.*, 2021; Carvalho *et al.*, 2022).

Resistance exercise training elicits morphological (i.e. increased muscle fiber/whole muscle cross-sectional area, change in muscle fibre pennation angle, and increase in the proportion of non-contractile tissues) and neurological (i.e. increased motor unit activation, firing frequency, and synchrony of high threshold unit) adaptations which contribute to changes in muscle hypertrophy, power, and strength (Egan and Sharples, 2023). Enhanced levels of muscle strength are associated with superior force-time characteristics, such as an increased rate of force development and increased external mechanical power, improved performance in general sport-related skills (e.g., jumping, sprinting, and change of direction), and a reduced risk of injury (Suchomel, Nimphius and Stone, 2016).

Between-sex differences (otherwise described as sexual dimorphism), referring to the mean systematic differences in function and structure between biological males and females, is observed across numerous systems within the human body (Lanciotti *et al.*, 2018). These differences become apparent during prenatal development, persist during childhood, and further diverge throughout puberty. This divergence leads to substantial differences between males and females in aspects that can influence exercise performance and adaptation (Hilton and Lundberg, 2021). These well-documented sex differences in anatomical, physiological, and performance factors may have significant implications for physical preparation in sports (Bassett *et al.*, 2020; Hilton and Lundberg, 2021). Whether these sex differences warrant a different approach to physical preparation for female rugby athletes or female athletes in general has not been thoroughly explored in the literature to date.

Positionality: My Professional Experience and Practice

The undertaking of research is not a discrete event, but an ongoing, iterative procedure, which can be understood as a mutualistic interplay between the investigator and the subject of investigation. This relationship can be encapsulated by the concept of 'positionality', denoting the premise that our individual antecedent experiences, convictions, and dispositions exert an influence on the research process (Bourke, 2014). Concurrently, the research process reciprocally reshapes our perspectives in a dialectic manner. Positionality aligns with the concept of reflexivity, a term which denotes the introspective consideration of the ways in which one's personal beliefs, values, and actions influence the generation, analysis, and interpretation of data (Jafar, 2018). Given my unique dual role as a 'pracademic' (practitioner and academic), it is contextually relevant that I provide a detailed exposition of my professional experience and practice.

For approximately a decade, beginning with an athletic development internship in Gaelic football during my undergraduate degree, I have been actively engaged in applied sports science, as well as fulfilling various strength and conditioning roles. Since then, I have worked with a diverse array of both male and female athletes, spanning disciplines such as Mixed Martial Arts, boxing, body building, powerlifting, sprint cycling, marathon running, and soccer. My experience covers a broad spectrum of performance levels, from youth development and recreational sports to national- and world-level competition. My roles ranged from providing basic sports science support to leading comprehensive athletic development programs. These applied practice roles have been in parallel to roles in research and academia, namely as a research assistant conducting clinical trials and as a lecturer in sports and health sciences. It is unquestionable that the practitioners, coaches, and academics with whom I collaborated in these roles have significantly shaped my professional attitudes and beliefs.

In my observation, and accepting this is anecdotal, a considerable number of coaches with whom I have collaborated espouse an androcentric perspective on physical preparation. That is, their convictions and practices were predominantly informed by resources and previous experiences related exclusively to male athletes. Regrettably, this approach extends to their work with female athletes, with coaches often using male performance characteristics as a reference point for comparison and scaling of physical preparation methodologies rather than considering female athletes from a distinct standpoint.

These practitioners also tend to perceive female athletes as inherently more susceptible to injury and generally 'less robust', often leading to an increased level of conservatism in their physical preparation strategies i.e. avoidance of high-load resistance exercise training. These coaches would frequently adopt divergent approaches to the physical preparation of male and female athletes at equivalent ages or performance levels, often prescribing lower relative load intensities for females. These practitioners also conveyed their belief that females respond more favourably to different training approaches than males. For instance, a prevalent assumption I encountered was that females respond better to lower loads and higher repetition ranges when targeting skeletal muscle strength and hypertrophy enhancement. This belief is commonly justified with a pseudoscientific reference to sex-related differences in muscle structure and function.

This observation led me to contemplate the factors contributing to this seemingly ubiquitous 'groupthink' among strength and conditioning practitioners regarding the physical preparation of female athletes.

In 2018, I took over as the head of athletic development with Rugby Academy Ireland, a private, full-time rugby academy preparing both male and female rugby athletes to enter professional rugby. Athletes from this program have graduated to compete at United Rugby Championship, International and Olympic (Sevens) level. This role entailed a substantial amount of daily direct interaction with athletes at both the collective and individual levels, fostering strong rapport with each athlete. Upon reflecting during this period, I observed that my interpersonal engagement with athletes varied, influenced predominantly by factors such as the athletes' personality types, cultural backgrounds, and crucially, their sex. I recognized an unconscious modification in my language, demeanour, and overall approach when interacting with female athletes. The strong rapport built with our female athletes prompted frequent discussions concerning their menstrual cycle symptoms and their potential impacts on their performance. I noted the absence of any monitoring programs related to the menstrual cycle in any previous role or organisation in which I had been involved. As someone committed to an evidence-based approach, I found a conspicuous scarcity of literature available to guide best practices pertaining to both the menstrual cycle in female athletes and the physical preparation of female rugby players. Basic research that one would expect to be easily accessible, such as player physical and performance characteristics and match demand characteristics, were notably absent in the context of women's rugby union. The sparse existing literature either focused on a different code, such as sevens, or on a non-comparable cohort.

Having noticed this lack of applicable research, I was motivated to pursue my PhD. My initial intent was to investigate the influence of the menstrual cycle on physical performance attributes and to determine whether the menstrual cycle phase affected widely used performance monitoring measures such as isometric mid-thigh pull, counter-movement jump, and sprint speed. Follow-up studies would have investigated the efficacy of novel physical preparation programs on performance outcome measures in female rugby union players. However, the impact of the COVID-19 pandemic significantly impeded access to both participants and testing facilities, rendering the proposed research studies unviable.

Despite its challenges, this obstacle provoked deep introspection on the role of the sports science researcher. I came to the renewed understanding that an essential function of the sports science researcher is to equip coaches and practitioners with impactful research that enriches their understanding and informs their practice. To accomplish this effectively, it is crucial to comprehend the attitudes, beliefs, and practices of the coaches in the field, while striving to fully grasp the real-world challenges and impediments they encounter in their practice. It is not our place as researchers to assume that we are best positioned to identify the "significant" questions in advancing athletic performance.

It is only by genuinely understanding the problems faced by practitioners that we, as sports science researchers, can design appropriate studies. These studies should aim to provide information that can be adopted and implemented by practitioners at the frontline of athletic development. Revisiting the notion of positionality, my dual experience as a coach and an academic has afforded me not only a nuanced understanding of the tangible challenges encountered by practitioners but also an appreciation for the complexities inherent in designing and executing ecologically valid sports science research. The necessity to conduct and effectively disseminate practically relevant research to enhance understanding and inform practice has been cemented by my ongoing work as a practitioner throughout my doctoral studies. This reaffirms my desire to delve deeper into this domain in the future.

Women's Rugby Union – Current Landscape of Literature

Despite the significant growth in the participation of women's rugby in the modern era, empirical research in this domain is arguably scant. For example, as of May 2023, simply applying the search string: "female rugby" OR "women's rugby" in PubMed returned ~140 results. In contrast, searching the term "rugby" returned >4500 results. A recent scoping review and Delphi study identified only 123 relevant sports science / sports medicine studies in the area of women's rugby (Heyward *et al.*, 2022). The majority of published research in this domain (~39%) focused primarily on the topic of injury, with only 26% and 21% of studies investigating physical performance, and match characteristics, respectively. Strikingly, of the available research, only 34% specifically examined rugby union. For the strength and conditioning coach, there is little evidence to draw inference from when designing physical preparation interventions, particularly in elite cohorts. Expert consensus has advocated for further research in the domain of strength and conditioning practices and efficacy in women's rugby (Heyward *et al.*, 2022).

Physical Performance Characteristics and Training-Induced Adaptation

A paucity of literature describing either the physical performance characteristics or the efficacy of physical preparation interventions in women's rugby union presents a clear challenge for the strength and conditioning coach. The prevailing literature, scant as it may be, is primarily constituted by cross-sectional studies (Posthumus *et al.*, 2020; Escrivá *et al.*, 2021; Harty *et al.*, 2021; Yao *et al.*, 2021) and longitudinal analysis of anthropometric and/or physical performance characteristics, examining changes across a one (Falk Neto, Parent and Kennedy, 2021; Curtis *et al.*, 2022), five (Woodhouse, Tallent, *et al.*, 2022), seven (Tucker *et al.*, 2021), and ten (Imbert *et al.*, 2023) year period, respectively.

Regarding anthropometric characteristics, the existing literature exhibits broad consensus, suggesting a trend of increasing body mass and growing heterogeneity in anthropometric characteristics. For example, the average body mass of tier 1 international players competing in the women's rugby world cup increased by 4.8% (79 vs. 83 kg) from 2010 to 2017 (Tucker *et al.*, 2021). Research on top-ranking international women's rugby union teams has reported discordant conclusions.

Anthropometric profiles of the English national team, ranked in the top two world rankings over the course of the five-year longitudinal analysis (2015-2019), displayed and upward trajectory in body mass, ranging from 62.5kg (scrum-halves) to 84.9kg (front-row) in 2015, increasing to 65.8kg and 91.7kg in the same positional groups by 2019, and was accompanied by a reduction in skinfold measures, ranging from 83.0-110.9mm in 2015 to 61.7-97.1mm in 2019 (Woodhouse et al., 2021). Conversely, an examination of the French national team over a decade (2009-2020), a team maintaining a top-three ranking for the majority of the data collection period, reported no significant differences in players' anthropometric profiles throughout this period. These incongruent findings indicate that anthropometric measures may not be crucial determinants of match success in women's rugby union.

However, the nature of these studies limits their generalisability in making inferences related to match success. The majority of the aforementioned studies simply reported cross-sectional and longitudinal analyses of anthropometric profiles in a single team and failed to investigate the relationship between anthropometric profiles and match outcomes. Body composition, as measured by skinfolds, has been shown in part to explain variances observed in relative ball carries and collision dominance in a top-ranked international cohort (Woodhouse, Bennett, *et al.*, 2022). Future studies may benefit from including multiple teams where possible and examining the potential role of anthropometrics as a determinant of match success.

Physical preparation programs are widely used by top-tier women's rugby union cohorts to enhance performance and reduce injury risks (Heyward *et al.*, 2020). Longitudinal analysis of elite-level players has reported a trend of increasing strength, with single leg isometric relative strength ranging from 2.39-2.81kg.bw^{-1} in 2015, increasing to 2.65-3.08kg.bw^{-1} in 2019, and improved sprint times over 10m (-1.5%) and 50m (-0.9%), respectively (Woodhouse, Tallent, *et al.*, 2022; Imbert *et al.*, 2023). This increased speed coupled with increasing body mass has resulted in players displaying increased momentum, that is, the product of body mass and velocity, which may have significant implications for collision forces and subsequent injury risk (Hendricks et al., 2014). For example, average momentum over 0-10m sprints ranged from 334.1(scrum halves) to 423.9kg.m.s^{-1} (second rows) in 2015, increasing to 369.1 to 461 kg.m.s^{-1} in 2019 (Woodhouse, Tallent, *et al.*, 2022) This may be of particular importance in women's rugby union as international expert consensus has highlighted injury risk area which requires further research (Heyward *et al.*, 2022), with many highlighting insufficiencies in current practices, and advocating for increased safeguarding in concussion management in women's rugby (Dane *et al.*, 2023; Spiegelhalter *et al.*, 2023).

Despite the adoption and perceived importance of physical preparation programs by coaches, studies investigating the efficacy of physical preparation interventions in female rugby union players have yet to be conducted. To my knowledge, only a single study has examined the effect of progressively increasing training load on power outcomes, assessed by counter-movement jump, but this was conducted in a rugby sevens cohort (Gathercole, Sporer and Stellingwerff, 2015). This research gap needs to be addressed to provide practitioners with ecologically valid data from which they can draw evidence-based inferences to guide their planning decisions.

Physical Match Characteristics

The advent and sophistication of Global Positioning System (GPS) technology in rugby union, has dissection of the physical characteristics of match-play. This includes measures such as running distances, velocities, accelerations, decelerations, and associated variables (Cahill *et al.*, 2013;

Cunningham *et al.*, 2016) Modern GPS technology also provides valid measures of collision events in rugby union (MacLeod *et al.*, 2018). These comprehensive datasets equip practitioners with valuable metrics pertaining to physical match demands and training load surveillance, thereby assisting in crafting appropriate physical conditioning interventions, which may enhance tolerance to the rigors of match-play, increasing performance and reducing injury risk (Foster, Rodriguez-Marroyo and de Koning, 2017; McLaren *et al.*, 2018). Match demands in men's rugby union are comprehensively documented across multiple playing levels (Austin, Gabbett and Jenkins, 2011, p. 14; Coughlan *et al.*, 2011; Read *et al.*, 2017) and age grades (Bridgeman and Gill, 2021). However, the literature describing the match demands of women's rugby union remains sparse (Heyward *et al.*, 2021), particularly at international level, with studies using lower ranked teams and small sample sizes (Suarez-Arrones *et al.*, 2014; Sheppy *et al.*, 2020).

The most comprehensive analysis of the physical demands of women's international rugby union to date (Woodhouse *et al.*, 2021a) delineates the differences between playing positions in high-velocity running (>5.5 m.s-1), accelerations, decelerations, and collisions. Expectedly, Outside backs covered the highest total (5283m) and high velocity distance (281m) with front rows covering the least total (3240m) and high velocity distance (14.5m). Notably, this sample cohort maintained a global ranking in the top two throughout the data collection period, with several years inclusive of professional athletes only.

The use of data derived from professional players may circumscribe the generalisability of these findings to the broader population of international women's rugby union players, as the majority are non-professional. Methodological heterogeneity in studies investigating international cohorts (Suarez-Arrones *et al.*, 2014; Sheppy *et al.*, 2020; Woodhouse *et al.*, 2021a), restricts further comparison and integration of extant literature. Discrepancies in methodological approaches across research, specifically regarding the inclusion/exclusion parameters and employment of velocity thresholds, impose challenges for direct comparisons. Such classification problems, stemming from a lack of consensus on velocity thresholds, may be further exacerbated in female team sports given the paucity of research (Sweeting *et al.*, 2017).

In summary, there is a paucity of studies that would assist strength and conditioning professionals in the creation and implementation of their physical preparation programmes. Existing research within this domain has predominantly concentrated on cross-sectional and longitudinal epidemiological analyses of injuries and the physical characteristics of match-play. Furthermore, the scarce studies that have explored physical performance characteristics have primarily emphasised anthropometric outcomes, mostly neglecting to explore the correlation between such performance characteristics and successful match outcomes. No studies have yet investigated the efficacy of a physical preparation intervention on performance metrics within a women's rugby union cohort. This gap in the literature underscores the need for further investigation in this field, which would provide practitioners with the necessary insights to aid in the development of efficacious physical preparation programs.

The Influence of Between-Sex Differences and The Gendered Sport Environment on Athletic Development

Between-sex differences, which denote mean systematic disparities in function and structure between biological males and females, are measurable across numerous systems within the human body. These discrepancies are discernible as early as prenatal development, persist during childhood, and diverge further throughout puberty. The culmination of these evolving differences yields significant disparities between males and females in aspects that can critically influence both exercise performance and adaptive responses. (Hilton and Lundberg, 2021).

Prenatal sexual differentiation commences around the seventh gestational week, when the sex-determining region Y (SRY) gene, also known as the testis-determining factor protein, initiates the formation of foetal testes in biological males possessing XY chromosomes (Nassar and Leslie, 2023). In contrast, biological females do not carry this gene, given its location on the short arm of the Y chromosome, consequently leading to ovarian development.

In the neonatal and early life stages—specifically, the first 3-6 months—human beings undergo a phenomenon referred to as "minipuberty." This process is a consequence of the activation of the hypothalamic-pituitary-gonadal axis, resulting in elevated gonadotropin and sex steroid levels (Lanciotti *et al.*, 2018). This surge, associated with "minipuberty," results in higher growth velocity in males during the initial six months of life, thereby exerting an "imprinting effect" on body mass index (BMI) and overall body weight (Becker and Hesse, 2020). Additionally, more than 3000 genes are differentially expressed in male and female skeletal muscle, which may influence their composition and structure (Haizlip, Harrison and Leinwand, 2015); for example, females display a higher proportion of type I fibres in certain muscles, such as the vastus lateralis and biceps brachii (Roberts *et al.*, 2018).

Although some have postulated the irrelevance of between-sex differences related to athletic performance prior to puberty (Tønnessen *et al.*, 2015), the phenotypical sex differences observed in skeletal muscle may elucidate the "male advantage" observed in children aged 6 and 9 years, as reflected in superior performance in broad jumps (9.5% further), push-ups (33% more repetitions in 30s), and grip strength (13.8% higher), respectively (Catley and Tomkinson, 2013; Tambalis *et al.*, 2016). The onset of puberty engenders the development of secondary sexual characteristics driven by a confluence of factors that culminate in chronically elevated circulating levels of endogenous gonadal hormones, including testosterone, oestrogen, and progesterone. Concomitant with puberty, males display typical testosterone levels that are at least 15-times greater than those of females, inducing changes in skeletal muscle mass, strength, and anthropometric measures (Handelsman, Hirschberg and Bermon, 2018), further widening the structural and functional sex-related disparities in the musculoskeletal system.

The between-sex differences influencing the capacity for exercise performance can be partially attributed to disparities in social play, but are predominantly driven by differing concentrations of gonadal hormones, specifically testosterone, oestrogen, and progesterone (McCarthy, Nugent and Lenz, 2017). These dimorphisms are particularly evident in the musculoskeletal system, specifically regarding body composition, that is, the quantity and ratios, and both lean mass and fat mass. On average, males exhibit 45% greater lean body mass and 30% less fat mass than females (Janssen *et al.*, 2000). Variations in muscle structure, as demonstrated by higher ratios of type II to type I fibres in males, are also evident (Haizlip, Harrison and Leinwand, 2015), and absolute muscular strength also differs, with males displaying 57% greater grip strength and 54% superior leg strength (Neder *et al.*, 1999; Bohannon *et al.*, 2019). Connective tissue properties also display dimorphism, resulting in 83% higher tendon force capabilities and 41% greater tendon stiffness in males (Lepley *et al.*, 2018). These differences culminate in what is referred to as the "male advantage" in sports, indicating that males, on average, demonstrate superior performance outputs across a majority of sporting disciplines (Hilton and Lundberg, 2021).

While the majority of differences in physical performance between males and females are due to innate biological differences (Hunter *et al.*, 2023), the impact of the “gendered” sport environment must also be acknowledged. Firstly, it is important to define operational terminology for this thesis. Where discussed, this thesis concentrates on delineating sex-based differences, specifically those associated with biological sex. The term "gender" is recognized as a socially constructed concept that encompasses a diverse array of gender identities. Consequently, the terminology "sex-based differences" is employed to explicitly denote the scope of this thesis, which is limited to the differences between biological males and females. This distinction is essential to avoid potential confusion arising from the conflation of the terms "sex" and "gender" within the thesis. It is noteworthy that sports are typically stratified according to sex rather than gender. The prevalent use of gender terminology in categorizing sports can arguably be considered outdated (Martínková *et al.*, 2022), rendering the application of sex-based nomenclature more suitable and accurate in this context where possible. Therefore, any use of the description “woman” or “women” in this thesis is used where it is the nomenclature of the sport, or refers to an individual who is a biological female, and in no way refers to, or assumes a specific gender identity.

Historically, women's sports have been systematically under-resourced compared to men's sports, leading to a significant disparity in the environments experienced by male and female athletes. This disparity may contribute to observable differences in physical performance between the sexes. Despite the increasing participation of females in sports, there remains a notable gap in engagement levels, with only 37% of females participating in sports activities at least once a week, compared to 45% of males (REF).

Moreover, females are markedly underrepresented within decision-making of sports institutions at various levels. In 2015, only 14% of top decision-making positions in sports federations across member states were occupied by females, with most countries reporting less than 20% female representation. This imbalance in leadership roles may lead to a deficit in advocacy and support for initiatives and funding in women's sports. In the realm of sports coaching, a pronounced sex disparity exists, predominantly favouring males. This gap in coaching may adversely affect the development and promotion of women's sports, as male coaches might not fully appreciate or prioritise the unique needs and perspectives of female athletes.

The portrayal of female athletes in the media further exacerbates this issue. Media coverage often emphasizes femininity and sexual attractiveness over athletic skill and achievement, contributing to the marginalization of women's accomplishments in sports and perpetuating stereotypes based on sex. Men's sports, conversely, receive significantly more media coverage, which impacts the visibility and commercial viability of women's sports.

This dichotomous environment between male and female sports has resulted in women's sports being underfunded and under-resourced. Female athletes face limited access to developmental pathways, particularly in terms of physical preparation, which may partly account for the significant differences observed in physical performance between the sexes.

The question of whether these between-sex differences, attributable to both biological and sociological factors necessitate an alternative approach to physical preparation for female rugby athletes, or indeed, female athletes more broadly, remains an under-explored area within the current academic literature.

The Menstrual Cycle and Hormonal Contraceptives

The primary gonadal hormones are a key determinant of the between-sex differences observed in humans resulting in differing anthropometric and performance characteristics between male and female athletes (Hilton and Lundberg, 2021). That said, the cyclic fluctuation of these primary sex hormones in females experienced by eumenorrheic females, that is, oestrogen and progesterone, or the manipulation of these hormones through exogenous ingestion via hormonal contraceptives (HCs), may, in theory, also have an influence on acute performance and chronic training-induced adaptations (Thompson *et al.*, 2020; J Kissow *et al.*, 2022).

In the context of athletic performance, female athletes who are post-menarche, that is, have experienced their initial menstrual cycle and menses, and are pre-menopausal can be generally partitioned into three distinct classifications pertaining to their hormonal milieu (Elliott-Sale and Hicks, 2018):

1. Eumenorrheic/Naturally menstruating: This encompasses those individuals experiencing a natural menstrual cycle with consequent ovulation as well as those exhibiting a naturally occurring menstrual cycle absent of ovulation.
2. HC Users: This group comprises those utilising HC measures.
3. Menstrual Dysfunction: This category denotes those with an absence or deviation from the norm in menstrual functionality.

These classifications are important for understanding and defining when attempting to draw inferences from relevant literature.

Overview of Menstrual Cycle Physiology

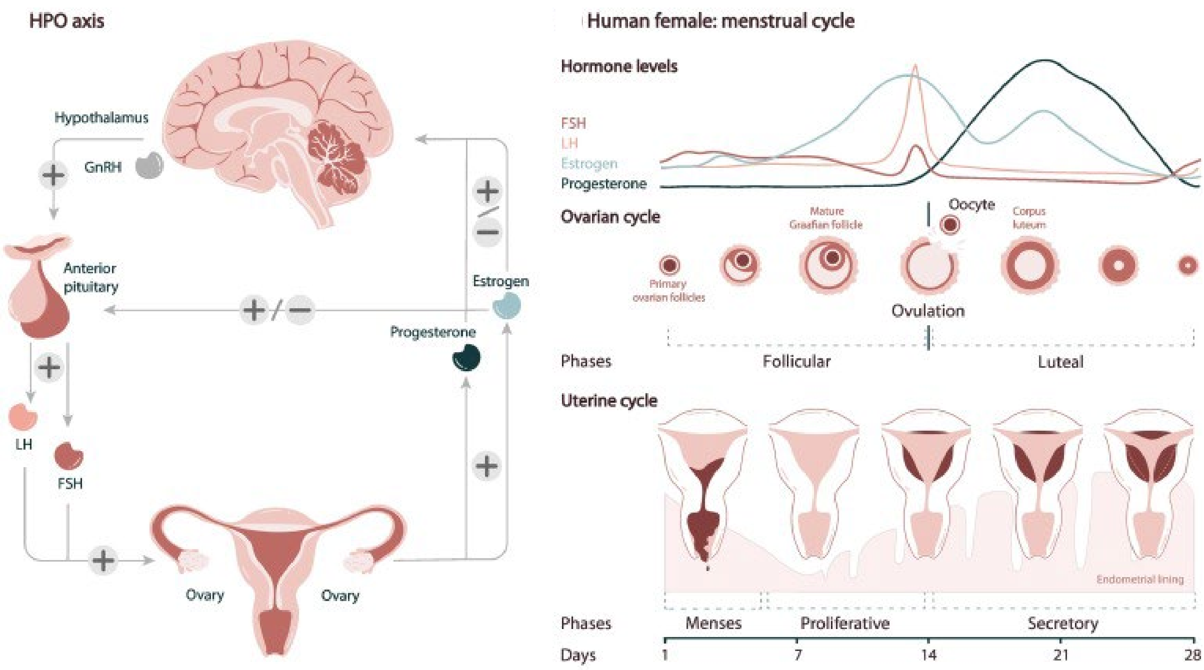

Figure 1. Overview of the Physiology of the Menstrual Cycle. Adapted from Gutierrez-Castellanos et al., 2022.

The menstrual cycle is regulated by the HPO Axis (also referred to as the HPG axis), that is, the interaction between the hypothalamus, pituitary gland, and ovaries (gonads). In brief, the menstrual cycle is described as a reoccurring cyclic series of events occurring in the reproductive system of biological females beginning at the onset of menarche i.e., the first period, preparing for the possibility of pregnancy, reoccurring approximately every 28 days until the onset of menopause (Constantini, Dubnov and Lebrun, 2005). The menstrual cycle is governed by cyclic fluctuations in gonadotropin-releasing hormone (GnRH), luteinizing hormone (LH), follicle-stimulating hormone (FSH), oestrogen, and progesterone (Elliott-Sale and Hicks, 2018). The menstrual cycle can be broadly divided into three different phases, the follicular (approximately days 0-14) and luteal (approximately days 15-28) phases, separated by the ovulation phase, each with their own distinct hormonal profile. The follicular and luteal phases may be further subdivided into the "early", "mid", and "late" phases (McNulty *et al.*, 2020). The early follicular phase commences (day 0) at the onset of menses i.e., the period, and is characterised by low endogenous concentrations of both oestrogen and progesterone. During this period, the secretion of GnRH from the hypothalamus stimulates the production of FSH and LH by the cells of the anterior pituitary gland. Increased levels of FSH in the early follicular phase stimulate the development of primary follicles in the ovary, eventually resulting in the formation of a single dominant follicle in the ovary. These developing follicles secrete oestrogen, resulting in a steady increase in the oestrogen concentration during the follicular phase. Despite GnRH acting on the anterior pituitary to secrete LH, concentrations of this hormone remain low during the follicular phase, due to the negative feedback loop effect of oestrogen on LH, that is, at low concentrations, oestrogen inhibits LH secretion in the anterior pituitary (Shaw *et al.*, 2010). Conversely, FSH is secreted in response to low oestrogen levels, which account for the decreasing concentration of FSH as the follicles mature, leading to increased oestrogen levels. As oestrogen levels continue to rise in the late follicular phase (approximately day 10), it has a positive feedback effect on the secretion of LH, leading to a spike in its concentration resulting in both a small increase in FSH concentration and more significantly, the release of the oocyte from the dominant mature follicle i.e., ovulation. Following ovulation, during the luteal phase, concentrations of FSH, LH, GnRH, and oestrogen all decrease as the dominant follicle degrades steadily and is referred to as the corpus luteum. As the corpus luteum degrades, it secretes the hormones oestrogen, progesterone, and inhibin (responsible for inhibiting the secretion of FSH), with the highest concentrations of these hormones typically observed at approximately day 21 of the menstrual cycle (Nédélec *et al.*, 2021). While a secondary spike in oestrogen levels occur during the luteal phase, the concentrations are much lower than observed during the mid- and late-follicular phases (McNulty *et al.*, 2020). During this phase, progesterone inhibits GnRH secretion from the hypothalamus and stimulates endometrial growth. In the event of non-pregnancy, full degradation of the corpus luteum results in low concentrations of oestrogen, inhibin, and progesterone. Low concentrations of progesterone in the late luteal phase result in GnRH no longer being inhibited, which, coupled with reduced endometrial integrity, leads to shedding in the endometrial lining, that is, the period, thus signifying the beginning of a new menstrual cycle.

The Menstrual Cycle and Exercise Performance

The cyclical fluctuations of endogenous sex hormones, namely oestrogen and progesterone, observed in eumenorrheic females have been hypothesised to exert a potential influence on both acute performance and chronic adaptations to exercise training (de Jonge, 2003; Constantini, Dubnov and Lebrun, 2005).

Oestrogen might influence several pathways and processes implicated in skeletal muscle recovery and adaptations following resistance exercise training, including protein turnover, myosin function, and satellite cell activity. However, the precise role of oestrogen in the regulation of skeletal muscle mass remains unclear, and the potential mechanisms mediated by progesterone remain largely unexplored (Colenso-Semple *et al.*, 2023). Oestrogen is likely to modulate protein synthesis/degradation pathways, as indicated by the observed differences in protein synthesis rates between postmenopausal females undergoing oestrogen replacement therapy and those who are not (Hansen *et al.*, 2012; Dam *et al.*, 2020). Through its influence on myosin proteins, oestrogen might impact muscle strength, as demonstrated by negative effects on the structure-function relationship of myosin and actin during activity, reduced force-generating capacity, and increased fatiguability in oestrogen deficiency conditions, such as those seen in rodent models and during menopause (Pellegrino, Tiidus and Vandenboom, 2022). Moreover, oestrogen may potentially modulate satellite cells by altering paired box homeotic gene 7 (a marker of satellite cell number), myogenic differentiation factor D-positive fibres, and DNA uptake of bromodeoxyuridine (Oosthuyse, Strauss and Hackney, 2023). These effects have primarily been demonstrated in ovariectomised rodent models receiving oestrogen replacement (Oosthuyse, Strauss and Hackney, 2023), and further study in human subjects is warranted.

Despite the aforementioned potential mechanisms, there is a seemingly paradoxical observation in the extant literature. Qualitative and self-reported data consistently indicate that a significant proportion of female athletes (approximately 80%) experience detrimental side effects of the menstrual cycle (Martin *et al.*, 2018a; Oxfeldt *et al.*, 2020) and perceive it as negatively impacting their sporting performance (Bruinvels *et al.*, 2020; Brown, Knight and Forrest Née Whyte, 2021). However, objective investigations into the impact of menstrual cycle phase on acute performance indicators suggest otherwise. Several systematic reviews, including meta-analyses, have demonstrated negligible to trivial effects of the menstrual cycle phase on athletic performance (Blagrove et al., 2020; McNulty *et al.*, 2020; Thompson *et al.*, 2020; Meignié *et al.*, 2021; Romero-Parra *et al.*, 2021). Nevertheless, a substantial body of research underpinning these analyses suffers from methodological limitations, such as small sample sizes, absence of appropriate control groups, and lack of blood sample confirmation of hormonal status, thereby imposing constraints on drawing definitive conclusions. The overall quality of research in this particular field remains relatively low, which further attenuates the robustness of these conclusions.

In summary, despite the existence of a theoretical framework suggesting a potential impact of the menstrual cycle on exercise performance, this is not supported empirically by the current, albeit low-to-moderate quality, body of evidence.

Overview of Hormonal Contraceptives

HCs involve the administration of exogenous hormones that disrupt the endocrine regulation of the female reproductive system, specifically by downregulating the secretion of endogenous gonadal hormones (De Leo *et al.*, 2016; Elliott-Sale and Hicks, 2018). HCs are utilised by a substantial percentage of individuals within both general populations (ranging between approximately 28-43%) and athletic populations (~40-51%) HCs are categorised based on the constituent hormones; combined HCs incorporate both oestrogenic and progestin components, whereas certain HCs consist exclusively of a progestin component. Delivery methods of HC include injection, transdermal patches, intrauterine devices, arm implant and vaginal rings, however, the oral contraceptive pill (OCP) is the most prevalent delivery method (United Nations, 2019; Elliott-Sale *et al.*, 2020). Combined OCPs function by lowering the endogenous concentrations of 17 beta oestradiol and progesterone (compared to the mid-luteal phase of the menstrual cycle) through negative feedback on gonadotrophic hormones, leading to chronic downregulation of the hypothalamic-pituitary-ovarian axis (Elliott-Sale *et al.*, 2020). Depending on the variation in the dosage of exogenous hormones throughout the OCP cycle, combined OCPs can be classified as monophasic (consistent dosage), biphasic (two dosage levels), or triphasic (three dosage levels). Further classification by "generation" is also common, which is determined by the form of progestin incorporated (Shahnazi *et al.*, 2014). Ethinyl oestradiol, the most commonly used oestrogenic component in OCP's is not "bioidentical" to 17 beta oestradiol, that is, they differ in their chemical and molecular structure (Liu *et al.*, 2022). This may be relevant when hypothesising the potential influences that HC's may have on athletic performance and adaptive responses to exercise training.

Hormonal Contraceptives and Exercise Adaptations

While it appears that HC usage does not exert an acute effect on athletic performance (Elliott-Sale *et al.*, 2020) or adaptation to resistance exercise training (Thompson *et al.*, 2020), interpretative limitations persist because of the predominance of low-quality literature characterised by small sample sizes, inconsistent standardisation, and inadequate familiarisation.

Current evidence regarding the influence of HCs on the adaptive responses to resistance exercise training is equivocal. Research outcomes vary from positive effects on molecular markers of skeletal muscle regulatory pathways, specifically MRF4 expression and satellite cell number (M. Oxfeldt *et al.*, 2020), to detrimental effects on muscle hypertrophy, strength, and inflammation measures (Ruzić, Matković and Leko, 2003a; Ihalainen, Hackney and Taipale, 2019; Riechman and Lee, 2022), to no significant impact on muscle hypertrophy, strength, and power outcomes (Nichols *et al.*, 2008; Wikström-Frisén, Boraxbekk and Henriksson-Larsén, 2017a; Dalgaard *et al.*, 2019; Romance *et al.*, 2019; Myllyaho *et al.*, 2021; Dalgaard *et al.*, 2022; Sung *et al.*, 2022a).

However, these studies present some interpretative issues owing to the grouping of participants who were utilising a variety of brands, with differing formulations and dosages, and in certain instances, different generations with varying progestin components.

The combination of participants using different types of OCPs leads to a wide range of endogenous sex hormone concentrations in group-level analyses, thereby potentially creating non-homogenous study cohorts (Elliott-Sale *et al.*, 2013). The influence of OCPs on adaptive responses, if present, is likely to be mediated by oestrogenic components. Therefore, grouping participants who are consuming varying dosages of exogenous oestrogen, exhibiting differing levels of androgenicity, or using progestin-only pills, presents methodological complications. Furthermore, genetic variations influencing tissue-specific sensitivity to oestrogen may introduce additional confounding factors into the analyses to elucidate the potential impacts of various contraceptive types (Wall *et al.*, 2014). These limitations highlight the need for more rigorous stratification of participants in future research. Improved precision in categorising subjects based on their specific HC usage is paramount for ascertaining more valid and reliable conclusions in this domain.

Such equivocal findings relating to the potential influence of HCs on athletic performance and adaptive responses to physical training highlight the lack of and need for evidence-based recommendations related to HC use in sportswomen. Further high-quality research is needed to delineate these potential effects and provide clearer guidelines for practitioners.

Coaching Practices, Athlete Buy-In and Interpersonal Relationships

The term 'athlete buy-in' `describes a sociocultural developed construct, prevalent within coaching discourse. This concept suggests that the realisation of the intended training effects, at least in part, is mediated through the cultivation of trust, relationships, and motivation among coaches, athletes, and the proposed intervention (Gearity and Kuklick, 2018). These foundational tenets are often perceived as vital components of the coach-athlete dynamic, with many viewing them as desirable attributes within this relationship. Despite its ubiquity in sports coaching circles, 'buy-in' remains an ambiguous term with insufficiently delineated parameters in the literature. Furthermore, it is arguably employed interchangeably and synonymously with the concept of motivation, thereby inviting debate around its precise meaning and application. This thesis undertakes an examination of key factors pertinent to physical preparation strategies for female athletes, with a specific focus on women's rugby union. The capacity of a coach to establish a compelling rapport with their athletes and motivate them to engage with evidence-based strategies has important implications for the practical application of the findings of this thesis. As such, it is of importance to elucidate the factors that could potentially influence a coach's ability to foster this critical engagement. These elements merit consideration not only for their relevance to the specific sporting context of women's rugby union but also for their broader applicability to the field of athletic development and performance enhancement in female athletes.

The motivational elements that influence an athlete's decision to participate in specific behaviours, such as adhering to a physical preparation program, can be expounded through various theoretical frameworks. Cognition-based models such as the Theory of Reasoned Action (Fishbein and Ajzen, 1975) and the Theory of Planned Behaviour (Ajzen and Madden, 1986) suggest that individuals deliberate on the consequences of their actions before deciding to engage or abstain from a certain behaviour. These theories are premised on the assumption that humans are rational beings and utilise readily available information for decision making. However, these models' unidirectional structure, which posits that cognitive processes follow a systematic and rigid sequence, is a limitation. Moreover, these are purely cognitive models that do not account for social, environmental, and other factors, such as competing behaviours, that can significantly influence a sporting context.

Competency-based theories, such as Bandura's Self Efficacy Theory (Bandura, 1977), propose that an individual's motivation to engage in certain behaviours is largely determined by their belief in their ability to execute the behaviour necessary to achieve specific performance goals. In other words, if an individual feels confident in their ability to perform a desired behaviour in a specific setting, they are more likely to partake in that activity. Athletes who perceive themselves as lacking technical proficiency in certain components of a physical preparation program may be less likely to engage with, or may actively avoid, that specific element.

Self-determination theory (Deci and Ryan, 2008), rooted in control-based theory, posits that individuals perform more favourably in the pursuit of goals when they are intrinsically motivated, thus fostering greater concentration, effort, and task completion. According to this theory, motivation and propensity to engage in certain behaviours depend on an individual's sense of autonomy, competence, and relatedness. In a sporting context, coaches can apply elements of self-determination theory by, for example, involving athletes in training-related decision-making processes (autonomy), ensuring task difficulty appropriateness (competence), and ensuring athlete comprehension of the dynamic correspondence of the physical preparation program (relatedness).

The Transtheoretical Model of Behaviour Change (Prochaska and DiClemente, 1983), grounded in stage-based theory, suggests that individuals' motivation to engage in certain behaviours resides along a stepwise spectrum. To incite behaviour change, individuals must progress from the precontemplation stage (unaware of any problem and thus lacking motivation to alter behaviours), through contemplation (becoming aware of the problem and the desired behaviour change), preparation (intending to take action), and action (practising the desired behaviour), ultimately arriving at either maintenance (working to sustain the behaviour change) or relapse (failure to maintain the behaviour change). The model can be critiqued for being descriptive rather than prescriptive, limiting its practical applications. Comprehending the behaviour change stage of athletes perceived to have low levels of buy-in may be crucial for implementing effective coaching interventions and avoiding misunderstandings leading to a breakdown in the coach-athlete relationship. For instance, a coach may misinterpret a low level of athlete engagement as apathy, leading to frustration, while the athlete is in the precontemplation stage and unaware that any issue exists.

Despite the respective strengths and weaknesses of various models, the Capability, Opportunity, Motivation-Behaviour (COM-B) model appears to most succinctly encapsulate the essential constituents of an effective behaviour change intervention. The COM-B model, a theoretical framework built on a comprehensive review of behaviour change theories, has gained considerable traction in public health and psychology arenas and is supported by the concept of the behaviour change wheel (Michie, van Stralen and West, 2011). This model asserts that successful behaviour-change strategies must aptly address the dynamic interplay between an individual's capability (the psychological and physical capacity to enact a specific behaviour), opportunity (external factors that either facilitate or obstruct a behaviour's occurrence), and motivation (cognitive mechanisms governing the inclination and readiness to engage in a behaviour). Within the sporting milieu, the COM-B model can be employed to comprehend and bolster athlete motivation, thereby potentially augmenting athlete engagement, performance, and adherence. For instance, interventions targeting the 'opportunity' component for female athletes might ensure equal access to training resources, while interventions addressing the 'motivation' component might accentuate team culture.

From a pragmatic standpoint, 'buy-in' is essentially the coach's subjective evaluation of an athlete's degree of engagement, trust, and belief in a physical preparation program. This evaluation is benchmarked against the coach's arbitrary expectations of what they consider to be the "optimal" or “required” level of buy-in. Consequently, this perspective is subject to the potential influence of coach bias and overlooks the range of interpersonal styles likely to be present in any given cohort (Poole and Schmidt, 2019). Nonetheless, the ability to foster motivation and engagement in athletes towards the physical preparation program remains a fundamental responsibility of the strength and conditioning coach.

Optimal training outcomes can be conceptualised as the product of a dynamic interaction between the athlete, coach, and proposed intervention. The degree of confidence an athlete places in their coach may have a significant influence on inciting particular behaviours. This argument is rooted not in sports-related literature, but rather draws inferences from seminal work in the domain of psychotherapy, wherein therapeutic alliance is esteemed as a preeminent common factor that underpins effective interventions (Wampold, 2015). The construct of alliance is conceptualised by three integral components1) the bond, 2) agreement about the goals of the therapy, and 3) agreement about the tasks of the therapy. Notwithstanding the critique that proponents of alliance predominantly draw from correlational research (DeRubeis, Brotman and Gibbons, 2005) meta-analytical reviews of over 200 studies, encompassing more than 14,000 patients, reported a moderate effect size (Cohen's d) of 0.57, linking alliance to the successful outcomes of individual psychotherapy (Horvath *et al.*, 2011).

The contribution of the therapist in achieving the desired outcome has been shown to be of critical significance (Baldwin, Wampold and Imel, 2007), that is, highly effective therapists demonstrated a capacity to establish strong alliances with a broad spectrum of clients. Interestingly, the contribution of the patients did not forecast the outcome i.e., patients who were capable of forming superior alliances, possibly due to secure attachment histories, did not necessarily have better prognoses. Notably, patients with adverse attachment histories and tumultuous interpersonal relationships might derive substantial benefit from a therapist capable of establishing alliances with challenging clients. Restricted likelihood (a statistical approach used to obtain a more robust and reliable estimation of the between-study variance) meta-analyses have further supported these findings (Del Re *et al.*, 2012).

Applying this insight to athlete-coach dynamics, the effectiveness of the coach in fostering a strong relational alliance across a diverse range of athletes may be an important factor. Notably, I would contest an athlete's ability to form robust alliances may not predict better outcomes in performance. Rather, athletes with complex interpersonal histories may benefit greatly from a coach who excels in building alliances with individuals who display relational difficulties.

The interplay between athletes and their beliefs regarding the effectiveness of the training intervention may be a pivotal determinant of training outcomes. The influence of athlete belief in the efficacy of an intervention is demonstrated by the positive effect of a placebo (a psychobiological response to a purported beneficial treatment) on sports performance (Hurst *et al.*, 2020). In a meta-analysis of 32 studies encompassing over 1500 participants investigating placebo effects on sports performance, Hurst et al. reported a pooled effect size (Cohen's d) of 0.37. Interestingly, the moderating effect of preconditioning procedures involving the administration of the placebo following surreptitious augmentation of perceived performance on previous performance was found to have a large effect on performance (d = - 0.82). Simply put, if an athlete's performance improvement is credited to the placebo before re-administration, the athlete is likely to excel in future performance, believing that the placebo is beneficial. In a coaching context, it could be posited that a coach's competence in elucidating the dynamic correspondence of the physical preparation program, that is, the training methods potential to translate to increased sports-specific performance (Suarez *et al.*, 2019), may exert a positive influence on athletic performance and the adaptive response.

The same meta-analysis also showed the antithesis of placebo, i.e., nocebo (a psychobiological response to a purported harmful treatment) can also negatively affect performance (d = 0.37), again highlighting the key role an athlete's appraisal of the efficacy, influenced by socio-environmental cues and coach-athlete communication (Beedie, Foad and Hurst, 2015; Davis, Hettinga and Beedie, 2020;

Roelands and Hurst, 2020) of an intervention may play in performance based outcomes during training, and subsequent training-induced adaptations.

In the context of sportswomen, a meta-synthesis has shown that females display an increased prevalence of deleterious beliefs, motivations, and hesitancies towards resistance exercise training which may act as barriers to engaging in this aspect of physical preparation (Vasudevan and Ford, 2022). Sex-, social-, and knowledge-based factors constitute significant barriers to engaging in resistance exercise training, with fear of hyper-muscularity, perceived lack of support/judgment from peers, and inadequate technical understanding and proficiency reported as main deterrents from engaging in resistance exercise training.

However, this synthesis analysed data from a broad spectrum of demographics including for example, clinical (Tulloch *et al.*, 2013) and older-adult (Fleig *et al.*, 2016) populations, which limits inferences to athletic populations. Studies on athletic populations have focused mainly on bodybuilders (Worthen and Bunsell, 2009; Worthen and Baker, 2016), ballet dancers (Rosenthal *et al.*, 2021), powerlifters (Foyster *et al.*, 2022), and weightlifters (Brace-Govan, 2004). The relevance of certain studies may be contested when considering their application to the context of rugby union, as they primarily emphasise aesthetic outcomes (such as bodybuilding), while athletes engaging in barbell sports (powerlifting and weightlifting) might exhibit a bias towards resistance exercise training that is not typically characteristic of rugby union players, hence, potentially skewing the applicability of these studies. Investigations involving collegiate-level recreationally active (Hame and Bixby 2023; Hurley et al. 2018; Peters et al. 2019) and athletic (Gilson, Chow and Ewing, 2008) populations have observed similar barriers as reported in previously mentioned cohorts, and may offer meaningful comparative insights relevant to female rugby union demographics.

While the barriers identified by these populations broadly align with the primary findings of the aforementioned meta-synthesis, they also delve into crucial factors that contribute to successful participation and 'buy-in' to resistance exercise training. These factors could potentially offer practical benefits in a coaching setting. One salient element of sustained engagement and adherence appears to be a favourable time-effort relationship — the perception that the benefits accrued from resistance exercise training are commensurate with the time and effort invested (Harne and Bixby, 2005; Hurley *et al.*, 2018). Promotion of increased self-efficacy, with an emphasis on self-mastery (Deci and Ryan, 2008) i.e., the belief that one either possesses or has the potential to develop greater technical competence in a specific skill (in this case, resistance exercise training), could also enhance willingness and motivation to participate in physical preparation interventions, and reduce fear of social judgement and technical incompetence (Peters *et al.*, 2019).

As previously established, the capacity of a coach to articulate the advantages of a physical preparation program and foster a relationship of trust with the athlete is arguably pivotal to the training process. In this context, it is important to acknowledge that there may be differences between males and females in communication styles and strategies that have implications for the coach-athlete relationship (Baird, 1976; Freed, 1996). This evidence suggests that sex-differences may be present in group communication settings with males tending to be more task-orientated, display increased verbal activeness and aggression, and being less suggestible (Baird, 1976). Conversely, females, on average, are less competitive in group contexts, more expressive of emotions, and display an increased perceptive ability of the emotional state of others (Freed, 1996). Additionally, females tend to demonstrate an increased propensity for self-disclosure (Dindia and Allen, 1992) and responsiveness to non-verbal communication (Epstein, 1986; McClure, 2000; LaFrance, Hecht, and Paluck, 2003). These differences, if present, could warrant varied coaching strategies and interpersonal approaches between male and female athletes. Considering the general differences in psychosocial processes between the sexes, these variations could translate into distinct interpersonal characteristics, with noteworthy implications for practitioners. However, it is essential to emphasise that these differences are arguably minor and are mediated by environmental and contextual factors (Canary and Hause, 1993). Moreover, it is probable that inter-individual variability in interpersonal characteristics, irrespective of sex, is substantial and must be considered alongside average between-group sex differences. The literature is yet to provide a comprehensive understanding of whether distinct differences in communication styles exist between male and female athletes (Sullivan, 2004).

Thesis Aims

The aim of this PhD thesis is to employ a mixed-methods approach to broadly investigate considerations relevant to between-sex differences in physical preparation, focusing specifically on factors relating to female athletes, examined through the lens of women's rugby union.

Aims:

- Investigate attitudes, beliefs and practices of elite international women's rugby union strength and conditioning coaches towards between-sex differences in physical preparation (Chapters 2 and 3)
- Investigate the prevalence of HC use and menstrual cycle-related symptomology in female rugby union players (Chapter 4)
- Investigate the physical match characteristics of elite-level international women's rugby union (Chapter 5)
- Investigate and quantify between-sex differences in baseline performance characteristics relating to body composition, power and strength outcomes (Chapter 6)
- Investigate whether between-sex differences exist in hypertrophy, power or strength adaptations in response to resistance exercise training (Chapter 6)
- Investigate whether HC use influences hypertrophy, power or strength adaptations in response to resistance exercise training (Chapter 7)

Chapter 2 – Study 1

‘There’s a perfect way to do things, and there’s a real way to do things’: Attitudes, beliefs and practices of strength and conditioning coaches in elite international rugby union.

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Abstract

Optimal physical performance is a product of specific and tailored training. There are well-established sex differences in anatomical, physiological, and performance factors between biological males and females, which may have implications for physical preparation. A potential knowledge gap exists in relation to sex-specific differences in physical preparation because practitioners largely rely upon empirical evidence collected in male subjects for reference when devising interventions for female athletes. Therefore, this study explored the attitudes, beliefs and practices of strength and conditioning coaches (n=8; M/F, 6/2) in elite level (international) women’s rugby union using semi-structured interviews (mean± standard deviation duration 59±15 min). The interviews explored differences in coaching elite female rugby players compared to males, with specific focus on training methodologies and understanding of pertinent aspects of female physiology. Reflexive thematic analysis was utilised to generate a rich qualitative dataset. Analysis resulted in the identification of higher order themes: *developmental stage of women’s rugby, physical preparation, and education.* Additional subthemes were created to facilitate organisation and presentation of data. The majority of coaches consider sex-specificity when devising physical preparation interventions as a function of training experience, rather than physiological between-sex differences, yet there were conflicting, and often erroneous understanding female-specific considerations. To the authors knowledge, this is the first study to investigate attitudes, beliefs, and practices in elite level strength and conditioning coaches regarding sex-specific differences, and as such, illustrates the current understanding and opinions of practitioners in international level women's rugby union.

KEYWORDS

hormonal contraceptives; menstrual cycle; physical preparation; professionalism; sex differences; training;

Introduction

Women's rugby union is one of the fastest growing demographics within rugby union, experiencing significant increases in participation numbers in recent years (worldrugby.org). Despite the large growth observed in women's rugby and the professionalisation of the men's game almost three decades ago, the majority of 'elite' female rugby union players i.e. internationals, participate as amateurs ('Women's Survey: Who's Playing the Game?', 2018). Total and relative running demands i.e. distance covered and velocities achieved, differ between the men's and women's game (Woodhouse *et al.*, 2021a). Collision frequency has been reported as similar (Woodhouse *et al.*, 2021a), or higher in the women's game (Nolan, Curran, *et al.*, 2023). Women's rugby union has also been observed to adopt more possession-driven attacking tactics compared to increased kicking frequency in the male game, resulting in a more open and continuous style of play (Hughes *et al.*, 2017). These factors may warrant differing approaches to physical preparation between the male and female athletes in their respective codes.

Appropriate physical preparation and training is an integral element of long-term athletic development (Ford *et al.*, 2011; Lloyd *et al.*, 2015a). There are well-established between-sex differences in anatomical, physiological, and performance factors (Bassett *et al.*, 2020; Hilton and Lundberg, 2021), which may have implications for physical preparation. Females also display differing hormonal profiles compared to males at rest and in response to exercise, which may also potentially influence performance (de Jonge, 2003; Constantini, Dubnov and Lebrun, 2005; Lebrun, Joyce and Constantini, 2020).

The cyclic fluctuations of endogenous sex hormones i.e. oestrogen and progesterone, experienced by eumenorrheic females may theoretically influence acute performance and chronic adaptations to exercise training, yet the evidence for this is equivocal at present due to the lack of a sufficient number of high quality studies (McNulty *et al.*, 2020; Julie Kissow *et al.*, 2022). Hormonal contraceptives alter the endogenous hormonal profile of females and this may also influence adaptive responses to exercise training (Ruzić, Matković and Leko, 2003a; M. Oxfeldt *et al.*, 2020; Dalgaard *et al.*, 2022; Riechman and Lee, 2022), but the influence has not yet been fully elucidated again due to the paucity of high quality studies (Elliott-Sale *et al.*, 2020). Qualitative and self-reported data suggest that a high prevalence of female athletes experience negative side-effects of the menstrual cycle (~80%) and hormonal contraceptive use (~24 to 40%), which may negatively influence performance in acute contexts.(Martin *et al.*, 2018a; Nolan, Lynch and Egan, 2020; Oxfeldt *et al.*, 2020) Lastly, between-sex differences in muscle fatigability (Hunter, 2016), and injury rate profiles (Zech *et al.*, 2022) have been observed.

These observations suggest a possible need for sex-specific physical preparation, but whether these between-sex differences do indeed necessitate differing methodological approaches to optimal physical preparation is yet to be fully explored. In response to matched resistance exercise training interventions, males and females respond similarly in terms of strength and hypertrophy outcomes (Roberts, Nuckols and Krieger, 2020), but this response is largely observed from untrained and recreationally-active individuals, which limits the inferences for athletic populations.

Given the general lack of evidence-based guidelines in the domain of sex-specific requirements for physical preparation, the present study explored the attitudes, beliefs and practices of strength and conditioning coaches in elite level (international) women's rugby union, with specific focus on training methodologies and understanding of pertinent aspects of female physiology. Exploration of between-sex differences, if any, in their approach to the preparation of female athletes will enable the identification of unique challenges faced by elite level practitioners, while also identifying any pitfalls or gaps in their current knowledge, which will inform both research and practice in the future.

Research Philosophy, Design, and Methods

Research Philosophy and Study Design

As pracademics (practitioner-academics) concerned with the generation of practically-meaningful insight, this study was underpinned by a pragmatic research philosophy (Giacobbi, Poczwardowski and Hager, 2005). Pragmatists adopt a practical approach to investigation, rejecting both pure positivism (i.e., the existence of a single reality and universal truths that can be objectively measured) and pure constructivism (i.e., reality is constructed by individuals and groups with no research finding more 'correct' than another), while not committing to any specific ontological or epistemological view. The present study addressed a relevant applied issue and did not assume an unbiased interaction between authors and data. Rather, the lived experiences of the authors were acknowledged, and the authors were considered co-constructors of knowledge, aided by their own experience leading, assisting and performing in elite sport.

Participants

Following ethical approval from Dublin City University Research Ethics Committee (permit number: DCUREC2020/283), eight strength and conditioning coaches in elite level (international) women's rugby union were recruited utilising a purposive, criterion sampling approach (Palinkas *et al.*, 2015). Invitations were extended to the thirteen highest ranked international women's rugby union teams as per world rugby rankings on March 1st, 2021 (worldrugby.org) via email to the respective rugby unions. Inclusion criteria stated that the participants had to be the current 'lead' strength and conditioning or athletic development coach for a senior international women's rugby union team, or have held that position within the previous 12 months. Participants' characteristics have been summarised in Table 1, which has been presented to ensure anonymity of participants is maintained.

Table 1. Descriptive Characteristics of Participants

Sex	n=8 (6 male, 2 female)
Age	35.7±5.4 y (range, 31 to 46 y)
Location	6 Northern Hemisphere, 2 Southern Hemisphere
Education Level	Bachelor's Degree, n=3 Master's Degree, n=5
Number of Years Coaching	13.3±4.7 y (range, 7 to 21 y)
Number of Years Coaching at International Rugby Level	6.5±6.3 y (range, <1 to 16 y)
Current or Former Rugby Player	Yes, n=7 No, n=1
Number of Teams Previously Coached	11.6±7.7 (range, 4 to 25)
Number of Female Teams Previously Coached	4.8±4.9 (range, 1 to 14)
Coached in Sport Other than Rugby?	Yes, n=7 No, n=1
Coached Youth Athletes?	Yes, n=7 No, n=1

Data reported as mean±SD where appropriate.

Procedures

Semi-structured interviews were utilised to allow for rich exploration of the key research questions, while also permitting flexibility to follow alternate lines of inquiry that emerged during the interviews. This process has been previously utilised to obtain qualitative data for the experiences of strength and conditioning coaches (Bell *et al.*, 2021). Prior to data gathering, a semi-structured interview guide was developed and informed by relevant literature and refined using pilot testing. Pilot interviews were conducted on two separate coaches (1 male, 1 female), which resulted in alterations to the interview guide to ensure alignment of questioning with study aims and objectives. These alterations consisted of modification of question structure and addition of probes to the interview guide. The interview guide consisted of introductory, central and closing questions, utilising a pliant approach to encourage meaningful discourse and ensure rich exploration of participant experiences. The interview guide addressed two distinct research questions; i) Do coaches use differing physical preparation strategies between sexes, and what influences these differences, if any, and ii) Do coaches have differing interpersonal interactions between male and female athletes? Due to the significant quantity of data gathered from these interviews, the themes relating to interpersonal interactions will be the subject of a separate report in order to enable appropriate depth of discussion for both research questions.

Detail-orientated probes were used to enhance the insights provided by the participants (Sparkes and Smith, 2013). For example, these included *'Can you explain exactly how you implemented that*?' or *'Why did you do that?'*. Clarification probes were used to further explore points that were unclear or vague (Quinn Patton, 2014). These included using phrases such as *'Just to be clear, can I confirm that when you say X you mean…?'*. All interviews were conducted online via *Zoom* (Zoom, San Jose) by the lead author, with due consideration given to the methodological and epistemological issues that conducting interviews in this format presents (Howlett, 2022). Audio recordings were transcribed verbatim using *Happyscribe* transcription software (Happy Scribe, Dublin) and the transcripts were manually checked for accuracy by the lead author. Following transcription, all data were anonymised with a participant identification number assigned for the purpose of reporting. Interviews were conducted during the period April to October 2021 and lasted between 28:44 and 84:16 min (63:14±17:59 min:sec), resulting in 145 pages (72,294 words) of data (18.1±4.3 pages per interview).

Data Analysis

Data were analysed using reflexive thematic analysis utilising the framework provided by Braun and Clarke (Braun, Clarke and Weate, 2016) to ensure appropriate application of thematic analysis. Thematic analysis is used to identify, organise, analyse and report qualitative data sets into concise patterns, offering insights into lived experiences (Attia and Edge, 2017), and has been previously used to garner insights into experiences of strength and conditioning coaches (Radcliffe, Comfort and Fawcett, 2018; Weldon *et al.*, 2021).

The first stage of analysis involved ensuring of accuracy of transcripts and immersion in the overall dataset, consisting of repeated listening to recordings and reading of transcripts, leading to the generation of 'points of interest' and potential codes and themes. Transcribed data were imported to

NVivo Pro (QSR International, Doncaster) NVivo was used for the purpose of storing and organising the dataset, enabling the research process rather than being a key feature of the analysis per se. The NVivo software was not used to lead the analysis process, and consistent reading and re-reading of the original transcripts ensured the lead author did not become distant from the data or participants (Fossey *et al.*, 2002). All data were again thoroughly examined, and codes assigned to lines and/or paragraphs relevant to the central research questions. All codes were then organised into themes and subthemes (as nodes). Reflexive thematic analysis was utilised to analyse the data and refine themes and subthemes. Following reflexive thematic analysis, and reflecting the sixth phase of the data analysis process, a consensus was agreed upon by the research team and a report of main findings was produced. This phase was recursive and given the reflexive nature of the process woven into the entire process of data analysis.

Trustworthiness

The application of thematic analysis in sport and exercises sciences has been previously criticised (Braun and Clarke, 2019), so it is imperative that best practices are observed to ensure high quality data are reported. Verification meetings of the research team resulted in the alteration, merging, and deletion of themes and subthemes. Verification methods are recommended to improve trustworthiness of data (Morse *et al.*, 2002). Authors listed at positions two (PH) and three (AMN) of the research team acted as 'critical friends' to the lead author and discussed similarities and differences in interpretation of the data, challenging the lead author until a consensus was agreed, with author four (BE) acting as a moderator where needed, leading to further refinement of themes and subthemes.

Reflexivity & Positionality

The lead author utilised reflexivity throughout the research process which is described as 'an act of self-reflection that considers how one's own opinions, values and actions shape how data is generated, analysed and interpreted (Mortari, 2015; Attia and Edge, 2017). The following information provides context which may be used to assess credibility of this research and improve its transparency.

The primary research question was devised as part of a wider investigation by this research group into sex-related differences in athletic preparation. This area of applied research is largely understudied, particularly in the context of rugby union. The lead author has practical experience and interest in female-specific strength training, and understands the pertinent issues faced by practitioners in this domain. During the development of the interview guide, subsequent data collection and analysis, the lead author aimed to separate his own experience and beliefs from those held by the participants and to remain objective. The experience of the lead author allowed for a credibility with participants and facilitated the detection of lines of enquiry during the interview process that may otherwise be overlooked by an interviewer of differing background.

The positionality of the lead author may be viewed as a strength of this study. Positionality is aligned with reflexivity and understands that research is a process in which our own experiences shape and, dialectically, is shaped by the ongoing research process and its importance is increasingly recognised in research (Jafar, 2018). The background of the lead author offered him 'insider' status when speaking with participants and this is arguably invaluable to the conduct of the study (Hammersley and Atkinson, 2019; Tracy, 2019). The participants recruited may be viewed as an unknown group, who are regarded as hard to reach. This status offered subcultural legitimacy and allowed for initial access as well as the development of trusting relationships between interviewer and interviewees.

Results & Discussion

The aim of this study was to explore attitudes, beliefs and practices of strength and conditioning coaches in elite level (international) women's rugby union. The thematic analysis produced three higher order themes under the central organising theme of "Differing Coaching Approaches to Male and Female Athletes" (Figure 2). These higher-order themes and subthemes are presented in detail with anonymised quotes included to support discussion points and explicate the participants' experiences. Additional words are placed in parentheses to clarify intended meaning or provide further context where relevant. Punctuation was added to quotations to reduce ambiguity where required. Additional representative quotes for each subtheme are provided in the appendices.

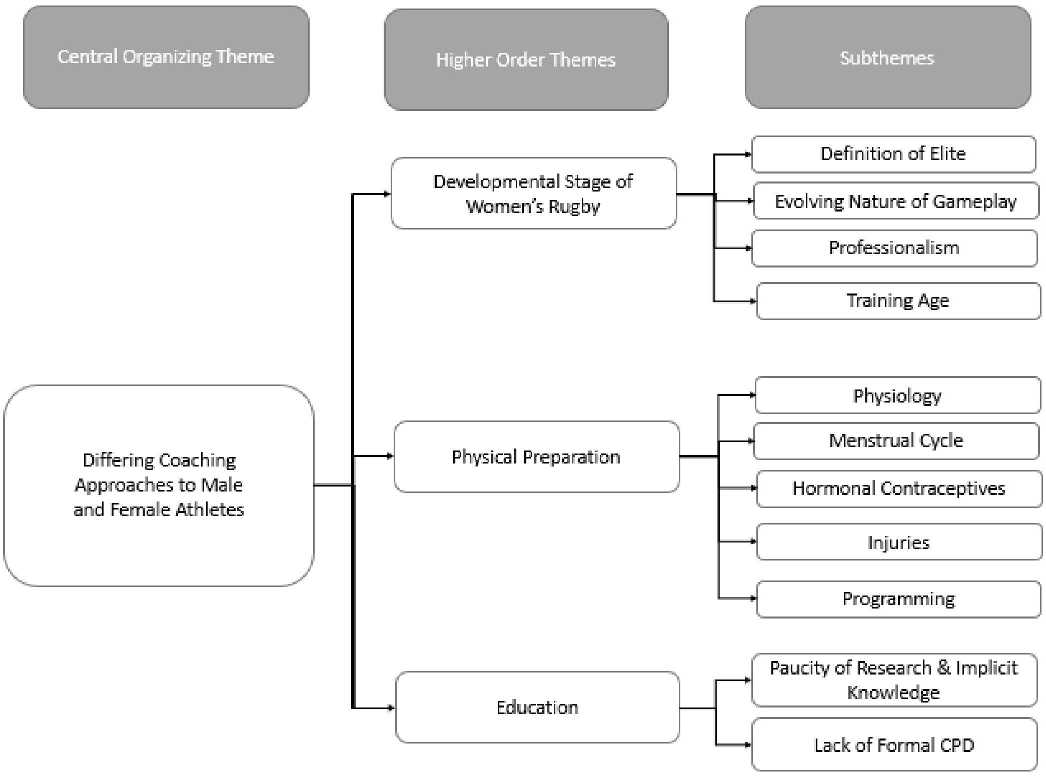

Figure 2. Schematic representation of central organizing, higher order, and subthemes.

Developmental Stage of Women's Rugby

Women's rugby is arguably in its infancy compared to the men's game (which turned professional in 1995), and is currently experiencing rapid growth in participation levels (Cummins *et al.*, 2020). Although some nations have professionally contracted players, the majority of elite level female rugby players partake under amateur status. The data generated four distinct subthemes concerning the development stage of women's rugby; definition of elite, evolving nature of gameplay, professionalism, and training age.

Definition of Elite

Overall, it was expressed that while the international arena represents the 'elite' of their sport, this definition holds differing connotations for males and females.

> *So, elite in a male is very different to elite in a female in my world at the moment... this is an elite female team, but it's an elite female team that's amateur that's only training twice a week.* (Coach 2)

The coaches also reported females can rise to international level much quicker, with different training and developmental pathways compared to males:

> *Whereas I found with senior females, just because they've probably got to that level without having had the years of experience in the gym or that big training age in resistance training.* (Coach 2)

> *You might get a girl who's playing at the top level who physically has no training age at all.* (Coach 6)

The term 'elite' in a sporting context has been argued to often be applied erroneously, both across and within sports, and athletes should not be automatically be enthroned with elite status by merit of competing at an international level (Williams, Day and Stebbings, no date). A more appropriate method of determining the status of an athlete should utilise objective markers of performance where possible compared to normative values i.e. personal bests and physical performance characteristics (McAuley, Baker and Kelly, 2022). However, this approach does not consider that elite athletes possess more than just higher than average physical attributes, with high levels of domain-specific skill execution also being imperative to performance. Physical testing batteries do not account for this. Taxonomies for classifying the status of athletes in sports science research have been posited for both physical (Pauw *et al.*, 2013) and skill-related attributes (Baker and Farrow, 2015), which may aid practitioners in conceptualising the current position their athletes reside upon the novice-elite spectrum, akin to employing a participant classification framework (McKay *et al.*, 2022).

Evolving Nature of Gameplay

Four of the coaches (Coach 2, 3, 5, and 6) acknowledged the differing nature of gameplay between the sexes as a key difference which influenced their practices. The ongoing evolution of women's rugby was considered a key issue in the development of future physical preparation strategies.

> *We've seen from 2014 to 2017 as there is only a three-year gap to [Women's Rugby] World Cups, the game had changed dramatically and I would hazard a guess in 2022, we're going to see that change again. We're going to see a more evolved, more conditioned [female] athlete that will have a higher tolerance to training and just be more conditioned and stronger.* (Coach 5)

There is a dearth of literature investigating the game demands of women's international rugby union. Because no study to date has directly compared international men's and women's teams using matched methodology, any interpretation of these data for between-sex differences is limited. Yet in other sports such as soccer where the women's game is more established, a divergence exists in which the men's game has higher running demands and intensities than their female counterparts (Bradley *et al.*, 2014; Cardoso de Araújo *et al.*, 2020). From the available evidence in rugby union, this divergence in the game demands between the men's and women's game also seems apparent, with the men's game having higher intensity running demands, with 'worst case scenario' total distances of ~154-184 m/min in men's international rugby compared to ~143-161 m/min in the women's game (Cunningham *et al.*, 2018; Sheppy *et al.*, 2020). The opinion that the women's game has intensified in recent years is also supported by empirical evidence showing an increase in sprinting and overall running demands in a five-year longitudinal study encompassing 2015-2019 (Woodhouse *et al.*, 2021a, 2021b). Total average distance covered in a game ranged from 2410 m (front row) to 4605 m (outside back) in 2015 compared to 3240 m and 5283 m for front rows and outside backs, respectively in 2019 (Woodhouse *et al.*, 2021a, 2021b).

The growth of women's rugby was suggested to have led to changing physical characteristics of players and increased heterogeneity of physiques.

> *You had quite a homogeneous body shape in women's rugby… Now, I think there's more girls playing rugby, which means you get more, you know, different shapes coming through, more suited. Plus, the roles are more specialised. You know, the teams will go after teams at scrum time now. So, you know, you've got a big, particularly powerful pack where historically it would be like very homogenous body shape.* (Coach 6)

Anthropometric profiles of international women's rugby players have significantly changed in recent years with athletes displaying lower levels of body fat, and greater levels of muscle mass (Woodhouse *et al.*, 2021b). Participation numbers in women's rugby are increasing year on year, so one would anticipate further diversification of anthropometric profiles with further increasing of muscle mass, which has been observed in other sports (Gonaus *et al.*, 2019).

Professionalism

The paucity of professionalism in women's rugby was identified as a major confounding variable that influenced and constrained the practices of the coaches.

> *But even if we were to look at the Six Nations and gather whatever data you want and you get an average of that. How true is that average when you've got a professional team, a semi-professional team and four amateurs?* (Coach 2)

As previously noted, female rugby players are sometimes viewed as "not truly elite" compared to their male counterparts. The confounding variable of professionalism must be acknowledged in this respect. If coaches aim to strive towards parity between the relative athletic abilities of male and female athletes, this parity may not be achieved under amateur conditions where factors such a training opportunities, facilities, and multidisciplinary support teams are not equivalent to professional status. Reported differences in coaching practice undertaken with male and female rugby players could be argued to not be due to biological sex of the respective athletes and the associated differences in anatomy and physiology, but rather is a result of constraints and extraneous factors resultant from the absence of professionalism and resources for the women's game.

Five coaches (Coach 2, 3, 4, 7, and 8) viewed the lack of professional status and decentralisation of players as a significant barrier in their practice.

> *We're getting girls once a weekend every three weeks. There was only so much we can really tweak because I say back to it was a camp weekend, and it was probably just a state of where we were at really as well. So, I wouldn't say it gold standard practice. And that's probably something that gets overlooked a little bit as well. You can't do everything when you see them once a month.* (Coach 8)

All coaches expressed the opinion that female rugby players generally have lower level of gym-based motor skill competence compared to their male counterparts, with Coach 8 stating *'Some of our six nations camps were spent teaching some girls to lift... Some girls needed to come in and learn how to push, pull and squat.'* The coaches' opinion was also that, in general, male athletes are exposed to structured gym-based training earlier in their sporting careers through school- and academy-based programs in adolescence, while female athletes generally do not get exposed to structured gym-based exercise until much later in their development, often not until adulthood.

Five coaches (Coach 3, 5, 6, 7, and 8) expressed views that female players have less training and athletic development opportunities available to them compared to their male counterparts due to differing structures and professionalism of the codes.

> *The problem is I was getting some girls coming to me for [Country] International set up at 24/25 [years old], maybe even older, who had very little support or even the support they were getting at their clubs wasn't of a standard most 15 year old lads would have been getting just because of the support and the funding behind it.* (Coach 8)

This lack of exposure may lead to weaknesses in fundamental athletic motor skill competencies that presents a barrier to long-term athletic development and success (Ford *et al.*, 2011; Lloyd *et al.*, 2015a, 2015b). Sex-based inequalities in sporting support structures has been posed as a significant barrier to both grassroot participation levels and progression of elite performers (Meier, Konjer and Krieger, 2021). Improved support structures, aligned to those offered to male players may enhance the athletic abilities of female players, theoretically resulting in improved performances, self-efficacy and player retention.

Training Age

While all coaches stated they do not differ their programming significantly due to sex-differences, it was universally acknowledged that any differences in their approach to physical preparation were generally due to a younger training age compared to males.

> *It's a massive difference [between males and females] in the sense of training age because they're not exposed to the level of training that you would need them to be.* (Coach 3)

Notably, the coaches expressed the opinion that the majority of 'elite' female rugby players have a very low training age pertaining to specific aspects of athletic development (i.e. gym-based training) when entering the international set-up. This suggests that female rugby players are under-developed with respect to currently adopted long-term athlete development models, which advocate for structured strength and conditioning training during adolescence (Lloyd *et al.*, 2015a).

Lower technical ability due to lack of training age was expressed by six coaches (Coach 2, 3, 5, 6, 7, and 8) as a significant influence on their approach to physical preparation.

> *They [have] got a very poor level, technically, especially in the gym, the level needed to be increased a lot to work safely also to perform and it's a real problem for us.* (Coach 7)
>
> *The technical and tactical characteristics and the physical characteristics are not quite as well emerged. You might get a girl who's playing at the top level who physically has no training age at all.'* (Coach 8)

These reported opinions again highlight the opinion that female athletes appear to not achieve sufficient stimulus from both their school-based physical education and club-based training to develop a high level of technical ability in the respective aspects of the athletic motor skills competency framework (Lloyd *et al.*, 2015b).

Physical Preparation

Females may require a different approach to physical preparation due to anatomical and physiological differences compared to males (Santos, Turner and Bycura, 2022). Female athletes display differing injury risk profiles (Stanley *et al.*, 2016; Sugimoto *et al.*, 2016), and factors such as endocrinological differences due to the menstrual cycle and hormonal contraceptives may lead to augmented adaptive responses to training, presenting unique challenges and requirements when designing and implementing a physical preparation program (Dalgaard *et al.*, 2019; Julie Kissow *et al.*, 2022). Five sub-themes are presented regarding physical preparation: physiology, menstrual cycle, hormonal contraceptives, injuries, and programming.

Physiology

Five coaches (Coach 3, 4, 5, 6, and 8) expressed the opinion that unique aspects of female physiology may lead to differences in adaptive responses to exercise training, and therefore influence the coaches' practices.

> *I guess if you look at physiology because of hormonal cycles, because of the nature of the muscle and everything else. Yes, women are going to respond differently…There may be some modalities of training that are more beneficial than others.* (Coach 5).

The opinions highlighted potential inaccuracies in the coaches' understanding of contemporary knowledge in female physiology as it pertains to neuromuscular adaptations to exercise training. Although it is theoretically possible that males and females respond differently to resistance exercise training due to divergent hormonal profiles, this is not yet supported by strong empirical evidence to date. When standardised for quantity of muscle mass at baseline before intervention, males and females do not display divergent outcomes for lower-body strength and hypertrophy in response to matched resistance exercise training interventions (Roberts, Nuckols and Krieger, 2020). Augmenting programming based upon assumptions of divergent adaptive responses due to between-sex differences in anatomy and physiology is not presently evidence-based. Decisions regarding physical preparation should, therefore, be based on better established factors such as training status (age).

Menstrual Cycle

The necessity to acknowledge the potential influence of the menstrual cycle was expressed by all coaches, with for example, Coach 5 stating; *'Your gut says it does [menstrual cycle impact performance], your athlete's gut says it does when you talk to them. They know their bodies themselves*,' yet four coaches (Coach 1, 3, 5, and 8) noted that they do not actively monitor the phases of the menstrual cycle with their athletes.

> *It's hard to attribute anything to the menstrual cycle because I don't know what their menstrual cycles are.* (Coach 1)

Despite calls advocating for raised awareness and monitoring of menstrual dysfunction in athletes (Hewett *et al.*, 2016), half of the coaches interviewed do not actively monitor menstrual function with their athletes. Monitoring of menstrual cycle status is a relatively cheap and efficient process that can identify individuals at risk of relative energy deficiency in sport (RED-S) and menstrual dysfunction, a pertinent risk factor for adverse health and performance outcomes in female athletes (Mountjoy *et al.*, 2018). With the increasing availability of cost-free menstrual cycle tracking applications, menstrual cycle monitoring can arguably be seamlessly adopted in a performance environment.

While all coaches expressed the opinion that the menstrual cycle may impact performance, they varied in their views when describing the mechanism by which they believe this effect occurs, with Coach 2 stating *'I definitely have some girls…when they're in the follicular phase, they're absolutely smashing it…when they're coming close to their menstrual cycle [sic] they don't feel as hot, they do take longer to recover… Half the time I don't know if it's a self-fulfilling prophecy of the fact that I've warned them on it [potential impact of menstrual cycle].'*

Again, these responses illustrate a potential lack of understanding of the current evidence regarding menstrual cycle phase and exercise performance. An apparent paradox is evident in the existing literature, wherein a consistent trend of qualitative and self-report data reports that female athletes experience a high prevalence of symptomology relating to the menstrual cycle and perceive it to negatively impact sporting performance (Bruinvels *et al.*, 2020; Brown, Knight and Forrest Née

Whyte, 2021), yet when examined objectively, menstrual cycle phase does not consistently affect acute performance indicators (McNulty *et al.*, 2020). However, it must be noted that the majority of research conducted to date in this domain is of low quality, with small sample sizes and clear methodological flaws (i.e. lack of appropriate controls, and lack of blood sample confirmation of hormonal status) and thus limits firm conclusions.

All coaches reported that they have adjusted planned training or implemented coping strategies with an athlete due to menstrual cycle symptomology, but noted this is done on an individual basis reactively rather than proactively.

> *We'll just drop a little bit in terms of what you're doing weights wise, or we'll change the training session to allow you to complete it a bit more effectively, or we'd apply a bit more choice around what they're doing in certain elements of training… or we'd take away an appearance or something like that and allow them to sleep or do things like that.* (Coach 6).

Based on current empirical evidence and best practice guidelines, adopting an individual approach to the development of menstrual cycle-related coping strategies is advisable (McNulty *et al.*, 2020). There is large inter- and intra-individual variability observed in menstrual cycle-related symptomatology (Martin *et al.*, 2018a; Brown, Knight and Forrest Née Whyte, 2021), therefore an individual, auto-regulated approach to symptom management is arguably superior to a generalised proactive strategy. A desire to implement so-called "phase-based training" was only expressed by Coach 1 who stated, '*I would love to do more phased based programming around each individual to maximize their maximize that training around the cycle… looking for ways to take advantage of the menstrual cycle and make it an ergogenic aid.'*

As previously noted, there are currently no evidence-based guidelines or methods to prescribe training based on a specific phase of menstrual cycle. This coach displayed a belief that phase-based training would enable the coach to "take advantage" of the menstrual cycle. Although this sentiment has a potential theoretical basis (Julie Kissow *et al.*, 2022), the empirical evidence for superior outcomes adopting such an approach is currently scant. Regardless, the reasons expressed for not using phase-based training were predominantly based upon logistical feasibility, with four coaches (Coach 2, 6, 7, and 8) believing that phase-based training to be unfeasible and impractical to implement in a team sport performance environment.

> *There's a perfect way to do things and there's a real way to do things…we can't change the playing and training schedule based on someone's cycle because you've got 40 girls, you've got 40 different cycles going on. You've got 40 different degrees of symptoms, you've got people on contraception, et cetera, things like that.* (Coach 8)

Hormonal Contraceptives

Two coaches (Coach 1 and 8) stated that hormonal contraceptive use may influence performance, but were ambivalent in their opinions, with Coach 1 stating *'Whether or not they're on contraceptives also like throws in a whole other mix,'* whereas Coach 8 stated *'From a theory standpoint, I'd say yes [hormonal contraceptive impact on performance], but I never got a chance to actually practically apply it and see.'*

Hormonal contraceptive use does not appear to acutely affect athletic performance (Elliott-Sale *et al.*, 2020), yet the majority of literature to date is again of low quality, with small sample sizes, lack of standardisation and inadequate familiarisation, among important issues that limit interpretation. There is equivocal evidence regarding the influence of hormonal contraceptive use on adaptive responses to resistance exercise training with the currently limited evidence base showing positive i.e., molecular markers (M. Oxfeldt *et al.*, 2020), negative i.e., hypertrophy, strength, inflammation (Ruzić, Matković and Leko, 2003a; Ihalainen, Hackney and Taipale, 2019; Riechman and Lee, 2022), and neutral i.e., hypertrophy, strength, power (Nichols *et al.*, 2008; Wikström-Frisén, Boraxbekk and Henriksson-Larsén, 2017a; Dalgaard *et al.*, 2019; Romance *et al.*, 2019; Myllyaho *et al.*, 2021; Dalgaard *et al.*, 2022; Sung *et al.*, 2022a) outcomes relating to hormonal contraceptive users compared to non-users. Coaches should be aware that there are currently no evidence-based recommendations relating to adapting training approaches based on hormonal contraceptive use.

Six coaches (Coach 2, 3, 4, 5, 6, and 7) stated that they have never considered the potential effects of hormonal contraceptives on performance.

I've got to hand up and say that is one of my blind spots [hormonal contraceptives]. (Coach 5)

I have no idea [regarding hormonal contraceptives]. (Coach 7)

Three coaches (Coach 1, 4, and 8) expressed opinions on potential health concerns relating to hormonal contraceptive use, with Coach 1 stating *'from my understanding, from what I've read thus far is that using oral contraceptives create more harm than good.'*

Given the high prevalence of hormonal contraceptive use in athletic populations and their sometimes associated negative side-effects (Martin *et al.*, 2018a; Nolan, Lynch and Egan, 2020; Oxfeldt *et al.*, 2020; Clarke *et al.*, 2021; Engseth *et al.*, 2022), coaches or medical staff should monitor the prevalence of hormonal contraceptive use by their athletes and be cognisant of the potential influence of support staff, while also being aware of emerging evidence and best practice guidelines pertaining to hormonal contraceptive use within sport. The motivation for hormonal contraceptive use is personal and multi-faceted, and this must be considered when discussing hormonal contraceptive use with athletes (Clarke *et al.*, 2021).

Injuries

Six coaches (Coach 1, 2, 4, 6, 7, and 8) expressed the opinion that anatomical differences influence injury risk, with Coach 2 stating *'The only difference [between males and females] is really that I have is, you know, there are certain parts of the female body, I think, that are more susceptible to injuries,'* while Coach 6 specifically highlighted the quadriceps angle (Q-angle) as a significant risk factor, stating that '*The large Q-angle and the wider pelvis in tall female athletes does represent a genuine ACL [anterior cruciate ligament] risk.'*

The opinion expressed that females display differing injury profiles and are at higher risk of knee injuries, specifically anterior cruciate ligament injuries, is supported by the literature.(Zech *et al.*, 2022) However, the attribution of increase knee injury risk to Q-angle by several coaches displays a potential lack of understanding of current evidence related to female sports injury risk. When standardised for baseline height, males and females display similar Q-angles (Grelsamer, Dubey and

Weinstein, 2005) and static measures of Q-angle have questionable clinical significance (Skouras *et al.*, no date).

Programming

Overall, the coaches interviewed in the present study do not approach physical preparation differently for female athletes compared to males.

> *I wouldn't do anything different. Again, it's just more your expectations are different...we can still do the same program and still do the same running.* (Coach 3)

Based on the current, albeit limited evidence base, there is not yet a strong rationale for sex-specific differences in programming. Females respond similarly to males in strength and hypertrophy adaptions following matched resistance training protocols (Roberts, Nuckols and Krieger, 2020). A sexual dimorphism does appear to exist in acute fatigability during high intensity performance bouts, yet this has largely been observed in isometric based tasks rather than isotonic contractions (Hunter, 2016). Although this sexual dimorphism is observed in acute fatigue during isometric contractions, the same divergence is not observed in recoverability of neuromuscular function following dynamic and eccentric focused resistance exercise training sessions (Lee *et al.*, 2017; Marshall *et al.*, 2020; Morawetz *et al.*, 2020). Considering this, it would be ill-advised to train females differently to males based primarily on potential differences in fatiguability.

Regarding exercise selection, there is no strong evidence-based rationale for differing exercise selection for female athletes, and unsurprisingly all coaches stated that their exercise selections do not differ between players due to sex, with, for example, Coach 4 stating '*there's no difference in that [exercise selection].'*

Given the increased risk of anterior cruciate injury present in females (Hewett *et al.*, 2016), it may be prudent to ensure female athletes are following an appropriate neuromuscular training programs, incorporating lower body strengthening exercises with a specific focus landing stabilisation which has been consistently shown to reduce anterior cruciate injury risk in female athletes (Petushek *et al.*, 2019). However, the same advice would be pertinent for male athletes also.

Education

Given that sports science and elite sport is such a dynamic and evolving domain, it is imperative to understand what resources and strategies practitioners employ to ensure appropriate continued professional development (CPD). Two subthemes were identified, namely lack of formal CPD, and paucity of research and implicit knowledge.

Lack of Formal CPD

Coaches noted there is a lack of formal educational programs specifically regarding physical preparation of female athletes provided by their respective unions. Five coaches (Coach 1, 3, 4, 5, and 7) rely primarily on non-peer-review resources, with colleagues being used as the main source of education, as typified by Coach 5 stating *'In short, no [education provided by union]. It's been a reasonably steep learning curve, I would say, from some of our more qualified, more experienced male coaches.'* Coach 4 displayed aversion towards academic research, stating '*What you can't quantify, can't be published. And that's a huge issue. And where my issue with academia is, it is now how many papers can I publish versus what problems am I trying to solve?... there's not a lot of ground-breaking things have come out, so it's like I think it needs to go…I then go into talking to coaches and then watching presentations…[the presenter] provides like real life practical [information]. It doesn't matter about the study design. Hey, I did this, I did that. I don't care if it's statistically significant. My athletes got better. They improved on the field. I don't I don't need stats to tell me that.'*

The coaches displayed a clear desire to further understand the requirements of the female athlete, but most noted a clear lack of opportunity for CPD on this specific topic within their union. Social media and podcasts were viewed as a key resource for on-going professional development.

> *And then obviously in today's world, like social media and podcasts, and getting information out that way, I think right now that's kind of leading, leading the front on this topic anyways*. (Coach 1)

Although podcasts can be a valuable source of information, podcasts are unregulated non-peer reviewed platforms and the accuracy of information disseminated cannot be ensured. However, the use of peer-reviewed literature as a source of CPD was being utilised by four coaches (Coach 2, 3, 7, and 8), with Coach 2 stating '*Google Scholar a lot [for CPD]',* and Coach 7 stating *'I'm often going on PubMed [for CPD].'* The perceived lack of CPD offered, coupled with lack of utilising peer-reviewed sources suggests the respective unions engaging in formal educational opportunities, perhaps with innovative CPD offerings, for their practitioners would be advisable in this context.

Paucity of Research and Implicit Knowledge

The majority of coaches in this study arguably present an androcentric view of beliefs and attitudes towards conditioning practices in women's rugby union i.e., adopting practices from, and consistent with comparisons to, the men's game and male athletes. This perspective is most likely attributable to the viewpoint expressed by coaches relating to the lack of research in women's rugby. A prevailing opinion amongst the coaches was that a dearth of empirical evidence exists concerning the physical preparation of female rugby players, specifically concerning normative data regarding game demands and physical characteristics, with Coach 3 stating; *'There's not enough, evidence, or studies done on female sports,'* and Coach 6 describing; *'Relative difference between positional characteristics is also something we don't understand.'* All of the coaches expressed the opinion that there is little available research on females that can inform practitioners. This viewpoint does not accurately reflect the body of evidence. While females are underrepresented in sports science research, they still account for approximately one-third of sports science participants (Costello, Bieuzen and Bleakley, 2014; Cowley *et al.*, 2021), but it must be noted that within studies relating to strength and hypertrophy outcomes or in highly-trained individuals, female representation is arguably lower. Research regarding best practices towards female athletes is constantly evolving and practitioners should be offered platforms to aid them in keeping up to date with, and correctly interpreting such information.

Study Strengths and Limitations

These coaches provided their insight and experience of sex-specific differences, albeit evidently few, in their approaches to physical preparation. The position held, and experience of the coaches is a clear strength of this study, although, of course, employment status is not necessarily a good indicator of expertise or knowledge. Nonetheless, to the authors' knowledge, this is the first study to investigate attitudes, beliefs, and practices in elite-level strength coaches regarding sex-specific differences, and as such, illustrates the current understanding and opinions of practitioners in international level women's rugby union. The qualitative methods employed in this study allowed for flexible analysis of rich information in a systematic and precise way.

Although the elite status of the coaches is considered as a strength of this study, it could also be viewed as a limitation. The homogeneity in status of the coaches should lead to caution of interpretation and application of results to practitioners in rugby as a whole. The viewpoints expressed may not be similar to those held by sub-elite coaches, or those working with amateur athletic populations or within other sports. The merit of occupying a senior position with an elite team should not be assumed *de facto* to reflect high levels of competency and knowledge. Also, three-quarters of coaches interviewed were male and while this is representative of the current landscape at the international level, it may be viewed as a potentially biased viewpoint given the topic under investigation.

Conclusions

This study provides important insights and contextual evidence to the understanding of sex-specific considerations in the physical preparation of female rugby players from the perspective of elite-level strength coaches, which to date has not been explored.

Women's rugby was reported by the coaches to be of a lower standard compared to the men's game in terms of 'elite' status and professionalism. Coaches highlighted that international female players often presented with low technical ability and training age in gym-based movements due to lack of systematic support within their performance environment and in developmental pathways. The improving standard of international women's rugby was acknowledged and with this in mind, coaches should be cognisant of current longitudinal trends i.e., increasing running demands and increasing heterogeneity of anthropometric characteristics. Women's rugby is currently experiencing significant growth and it is imperative that unions ensure appropriate support systems and infrastructures are available for their growing female demographic to capitalise on this rapid expansion.

Overall, while coaches expressed there are some females-specific considerations they are cognisant of regarding physical preparation i.e. individual management of menstrual cycle symptoms, there was no significant difference in how they approached the physical preparation of females compared to males in terms of training methodologies. Differences in approaches to physical preparations are primarily driven by lower training age, and poorer technical ability of female athletes compared to males rather than distinct anatomical or physiological differences, a potential legacy of under-resourced developmental pathways, and support structures for female rugby players.

There were clear gaps in knowledge exhibited by the coaches regarding both the menstrual cycle and hormonal contraceptives. Coaches should be aware of the potential influences of the menstrual cycle and hormonal contraceptive use, and it would be advisable to implement appropriate monitoring systems pertaining to these aspects of female health and performance. Currently, there are no evidence-based guidelines which advocate for differing training methodology for female athletes, and it would be prudent for coaches to follow their current protocols but to be aware of the evolving research in this domain.

Coaches clearly strive to utilise an evidence-based approach where and when possible but reported often lacking the necessary supports or information to do so. Informal resources (i.e. social media and podcasts) and colleagues were identified as the primary sources of education that the coaches utilised. There was a perception amongst the coaches that empirical data in elite female athletes is practically non-existent. This misconception should be addressed in this population with the coaches also being encouraged to draw inferences from data in other elite female sports and populations, where appropriate. Rugby unions would be prudent to audit their current support systems for practitioner CPD and implement resources to address identified gaps in coach knowledge, specifically regarding female specific considerations i.e. menstrual cycle and hormonal contraceptive use. A women's rugby specific online educational resource e.g. a podcast series delivering high-quality educational content, delivered from domain experts may be an efficient and cost-effective strategy which employs a platform that is already accepted and utilised by practitioners.

In the previous chapter we focused on whether there were differences in coaching approaches of elite international strength and conditioning towards male and female athletes pertaining to the applied technical aspects of coaching i.e., physical preparation programming. The chapter primarily focused on the factors that coaches consider when devising and adjusting the technical components of their physical preparation programs. We argue that while coaches largely adopted an androcentric view of women's rugby, that is, their adopted methods are largely based on comparisons to the male game and male-focused research, any differences in their technical approach are mainly driven by factors such as lower training age and poorer technical ability of female athletes compared to males rather than distinct anatomical or physiological differences. We also established that coaches expressed there are some females-specific considerations they are cognisant of regarding physical preparation i.e. individual management of menstrual cycle symptoms, there was no significant difference in how they approached the physical preparation of females compared to males in terms of training methodologies, rather, approaches were simply scaled based on relative ability.

The aptitude of a coach to devise an appropriate physical preparation plan is integral to athlete development. However, as an athlete-facing practitioner, the coach's ability to establish and build rapport with their athletes is arguably of equal importance. In the following chapter, I will report the findings of the thematic analysis relating to communication and interpersonal approaches of coaches and whether these differ between male and female athletes. Viewing athletic development through the biopsychosocial lens enables us to realise the potential value of building a strong, appropriate interpersonal relationship between the athlete and the coach, enhancing the efficacy of athlete monitoring, increasing athlete buy-in, and ultimately enhancing adaptation and performance.

This chapter begins by evaluating relevant literature exploring sex differences in interpersonal strategies and barriers to physical preparation. It also highlights the key role that psychological beliefs may play in sports performance. The chapter then explains the methodology employed (reflexive thematic analysis) and presents the key themes which emerged from this analysis. These themes form the basis for the key arguments put forth in this chapter. The chapter will show that coaches perceive mean differences between male and female athletes, which leads to differing interpersonal approaches of these coaches. I argue that these perceived differences in psychosocial factors may lead to different barriers to effective athlete engagement in male and female athletes that practitioners should be aware of. The chapter concludes by reiterating the key perceived differences the coaches reported and highlighting key recommendations that coaches should be cognisant of in their practice.

Chapter 3 – Study 2

'Male Athletes Play Well to Feel Good, and Female Athletes Feel Good to Play Well': Attitudes, Beliefs, and Practices Pertaining to Communication and Interpersonal Approach of Strength and Conditioning Coaches in International Women's Rugby Union.

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Abstract

Effective communication and rapport building with athletes are key tenets of coaching. As the majority of empirical evidence to date has adopted an androcentric view of strength and conditioning, a potential knowledge gap exists regarding sex-specific differences in physical preparation and coaching approaches. Therefore, this study explored the attitudes, beliefs and practices of strength and conditioning coaches (n=8; M/F, 6/2) in elite level (international) women's rugby union using semi-structured interviews (mean ±standard deviation duration 59 ±15 min). The interviews explored differences in coaching practices for elite female rugby players compared to males, with a specific focus on the interpersonal aspects of the athlete-coach relationship. Reflexive thematic analysis was used to generate a rich qualitative dataset. Analysis resulted in the identification of higher order themes: *athlete engagement, and interpersonal approach.* Additional subthemes were created to facilitate the organisation and presentation of the data. The coaches in this study consistently perceived there to be important differences between male and female players in factors related to engagement and interpersonal approach. These factors resulted in coaches adopting differing coaching practices for male and female athletes. This study provides important insights and contextual evidence for the understanding of understanding of differences in the interpersonal relationships of female rugby players compared to male athletes from the perspective of elite-level strength coaches, which, to date, had not been explored.

Introduction

Women's rugby union is one of the fastest-growing demographics within rugby union, and can be described as an invasion field-based team sport consisting of intermittent bouts of high-intensity efforts (i.e. running, sprinting, tackling, rucking, mauling, and scrummaging) and periods of lower intensity activity (i.e. walking, jogging, and resting; Coughlan et al. 2011). Appropriate physical preparation and training are integral to increasing performance capacity and long-term athletic development (Ford *et al.*, 2011; Lloyd *et al.*, 2015a). Resistance exercise training is well-established as an effective method of increasing skeletal muscle hypertrophy, strength and power in athletic populations (Schoenfeld *et al.*, 2021).

Females display an increased prevalence of deleterious beliefs, motivations, and hesitancies towards resistance exercise training (Hame and Bixby 2023; Hurley et al. 2018; Peters et al. 2019), which act as barriers to engaging in this aspect of physical preparation. Athlete 'buy-in' is a socially constructed belief commonly used in coaching discourse to describe an overarching concept that produces intended training effects by developing trust, relationships, and motivation as the fundamental tenets, and is viewed a desirable outcome for coaches (Gearity and Kuklick, 2018). Both socio-environmental cues and coach-athlete communication influence an athlete's belief in the perceived effectiveness of an intervention, which may influence motivation, as well as subsequent performance and adaptation (Beedie, Foad and Hurst, 2015; Davis, Hettinga and Beedie, 2020; Roelands and Hurst, 2020).

There may be differences between males and females in communication style and strategy (Baird, 1976; Freed, 1996), in particular propensity to self-disclosure (Dindia and Allen, 1992) and responsiveness to non-verbal communication (Epstein, 1986; McClure, 2000; LaFrance, Hecht and Paluck, 2003). However, these differences have not been extensively demonstrated in athlete populations. Additionally, these between-sex differences are arguably minor and mediated significantly by environmental and contextual factors e.g., physical setting, cultural norms or societal expectations (Canary and Hause, 1993).

Effective coach-athlete communication and rapport may be of importance in female sports, specifically in monitoring pertinent indicators of health. Self-reported data suggest that a high prevalence of female athletes experience negative side-effects of the menstrual cycle (~80%) and hormonal contraceptive use (~24 to 40%), which may negatively influence acute physical performance (Martin *et al.*, 2018a; Nolan, Lynch and Egan, 2020; Oxfeldt *et al.*, 2020). Female athletes not only present the unique risk of menstrual disorders (Skarakis *et al.*, 2021), but also display higher prevalence of both disordered eating (Mancine *et al.*, 2020) and relative energy deficiency in sport (RED-S; Mountjoy et al. 2018). Female rugby players have reported that coaches should display awareness, openness, knowledge and understanding of female-specific health concerns in their interpersonal interactions with athletes (Findlay *et al.*, 2020).

Given the general lack of evidence-based guidelines in the domain of sex-specific requirements for physical preparation, the present study explored the attitudes, beliefs, and practices of strength and conditioning coaches in elite level (international) women's rugby union, with a specific focus on athlete engagement and interpersonal approaches to coaching. Exploration of differing coaching approaches to male and female athletes, if any, in their approach to these aspects of preparation in female athletes will enable the identification of unique challenges faced by elite-level practitioners, which will inform both research and practice in the future. This analysis was an extension of our previous work which described the attitudes, beliefs and practices of the current participants relating to technical aspects of coaching in women's rugby union and the factors which influence these aspects (Nolan, Horgan, *et al.*, 2023).

Research Philosophy, Design, and Methods

This study was supported by a pragmatic research philosophy (Giacobbi, Poczwardowski and Hager, 2005) and is an extension of the work described in chapter 2. Detailed descriptions of the research design, participant characteristics, procedures, and data analysis are provided in chapter 2.

Results and Discussion

Through exploration of attitudes, beliefs and practices of strength and conditioning coaches in international women's rugby union, the thematic analysis produced two higher order themes under the overarching theme of "Differing Coaching Approaches to Male and Female Athletes" (Figure 3). These higher order themes and subthemes are presented in detail with anonymised quotes included to support discussion points and explicate the coaches' experiences. Additional words are placed in parentheses to clarify the intended meaning or provide further context, where relevant. Punctuation was added to the quotations to reduce ambiguity where required.

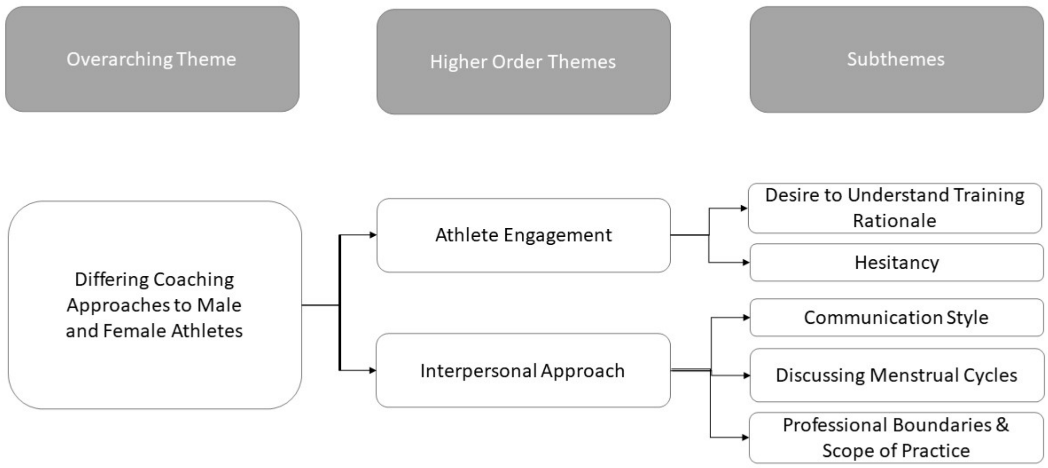

Figure 3. Schematic representation of central, higher-order and subthemes.

Athlete Engagement

There are potential differences between male and female athletes in psychosocial and motivational factors that practitioners should be cognisant of in a performance-orientated environment (Moreno Murcia, Cervelló Gimeno and González-Cutre Coll, 2008). Lack of athlete engagement can be problematic in elite sports and may lead to maladaptation and/or underperformance if not appropriately addressed (Neupert, Cotterill and Jobson, 2019). Two sub-themes were identified regarding engagement: desire to understand rationale, and hesitancy.

Desire to understand rationale

In this sub-theme, all coaches expressed the opinion that female athletes differed in their need to understand the rationale of training in order for the desired level of engagement to occur, and were more likely to question the prescribed methods than their male counterparts. Coach 5 noted how female athletes tended to ask more questions about the purpose and outcome of training than male athletes, stating:

> *I think, the guys will decide they want to lift heavy as soon as possible, but I think sometimes a female athlete is wanting to understand. That's like saying to the male athlete, sometimes run through the wall, they will say, 'yes I will run through the wall.' And the female athlete, you say run through the wall, they say 'well, why should I run through the wall? Can I not jump over it?'*

As a result, coaches described how they had to be more precise about their instructions and language when working with females as described by Coach 7 who remarked:

> *'The first and the main difference for me, it's about their approach of performance. When I finished with the men's team, I think I could say men ask to do things and first before [they] understand and the women have to understand before doing them.'*

The sentiment was elucidated in greater detail by Coach 6:

> *The difference is, I think a lot of the time is around that the detail of the information that needs to be provided and communicated, which I think, you know, historically and in the male game or in any male sport, it would have just been, rock up, and you go right this is what you're doing, crack on with it and they wouldn't want information. They just go, right what are we doing? Get on with it…When I started, you probably had a large group of female athletes who would want to know the how, the why, the what, the who, of every element of what you were doing so that they had clarity and they could be comfortable in delivering their best effort in that particular unit of training.*

Differences between male and female athletes in motivational factors and cognitive strategies used to aid athletic performance have been previously described, and may lead to differing coach-athlete dynamics and interactions (Philippe and Seiler, 2005; Moreno Murcia, Cervelló Gimeno and González-Cutre Coll, 2008). In general, females utilise higher levels of social support in a sporting environment (Crocker and Graham, 1995), and are more likely to perceive a task-orientated climate i.e., focus on the task at hand aiming to complete it to the best of their ability, as opposed to males who display a stronger ego orientation i.e., more likely to be competitive or concerned with proving their skills and superiority (Moreno Murcia, Cervelló Gimeno and González-Cutre Coll, 2008). These observations are from junior- and collegiate-level athletes, and so these may not be representative of elite female populations. Regardless, these differences could arguably lead to females engaging in a symbiotic 'peer-to-peer' relationship with coaches to better understand the task-specific requirements, whereas males may view coaches as an authoritarian figure who is to be impressed and therefore may be more hesitant to seek clarification, as not to appear inferior to their peers. Males also display higher levels of self-efficacy related to sporting tasks than females (Spence *et al.*, 2010), while also displaying higher levels of narcissism (Grijalva et al. 2015; Roberts et al. 2015). Therefore, males may be more likely to demonstrate unjustified levels of self-confidence in the execution of sports-specific motor tasks, such as resistance exercise training, and thus, less likely to seek clarification from practitioners.

Four coaches (Coaches 1, 2, 3 and 6) specifically noted that highlighting the role of dynamic correspondence (i.e., the ability of an exercise/program to directly affect sports performance) is a key element in justifying their rationale to the players. Coach 1 described a frequently experienced situation in which female athletes questioned the necessity of resistance exercise training, to which he/she retorts with, *'let's then talk about [to the player] how that strength can translate into their sport and help them as an athlete and help them stay in their sport versus sitting on the side lines due to an injury. So, I think focusing on what lifting, and what S&C can do for them and how it can help them become a better athlete, maximize their potential versus that fear driven place.'* This was echoed by Coach 3 who depicted regular conversations of a similar nature, in which he/she explained to his/her athletes, '*this is why we are doing this [resistance exercise training], this is how we do it, and it's going to help you in the lineout, and then the light will switch on. And then we get the buy in. Then we get that sort of OK, I have to lift this because, and this is the reason why, and this is how I need to do it, and this is how we transfer it. And when the light switches on, it goes [intent].'* Coach 6 simply stated he/she *'spent a lot of time working with players around education and really, really painting the pictures and allowing them to join the dots between physical training and rugby performance.'*

Given the stronger desire to understand task-specific components in females to achieve engagement, the ability to effectively communicate the role of dynamic correspondence to athletes is arguably a key skill that practitioners should possess. Practitioners should be able to elucidate key concepts to a wide range of diverse athletes, who are likely to have varying degrees of comprehensive ability (Boone *et al.*, 2020).

Hesitancy

For five coaches (Coaches 1, 2, 6, 7 and 8), hesitancy to engage in resistance exercise training was viewed as disproportionally prevalent in female athletes, resulting in a different coaching approach towards female athletes, exemplified by Coach 2 who stated, *'it takes a little while longer, I think, to get over that hump, to break down that barrier [fear of using high load in resistance exercise training] with females than it is with males… But I think to get to being able to tolerate heavy [resistance exercise training] takes just a little bit longer.'*

Females demonstrate higher levels of perceived barriers to engaging in resistance exercise training, such as fear of resultant hyper-muscularity and peer deprecation (Peters *et al.*, 2019). As previously noted, the ability of the practitioner to effectively communicate and educate the athletes is essential in overcoming these perceived barriers as described by Coach 7 who reported his/her belief that female rugby athletes *'don't want to be too strong. They don't want to get too much muscles. So we need to understand this is really why we do this kind of job, why strength, for example, is so important for them, at least to prevent [injury] but also because performance is our objective… [they] just need to know why they have to do it.'*

Body image and distorted understanding of the time course of adaptations to resistance exercise training were voiced as the main reasons for hesitancy to engage in resistance exercise training as summarised by Coach 1 stating he/she knows *'there is kind of a lot of stigma around working with some females who did have the fear, for whatever reason of getting bigger or how the training might affect that muscle mass and have that fear… but I did experience that stigma, that fear of maybe gaining* *weight or gaining muscle mass, more so with the women in the female population than I did with the men.'* This experience was also disclosed by Coach 2 who expressed that female players *'just think, you know, lifting weights, I'm going to be huge,'* and by Coach 6 who acknowledged, *'it certainly was in female rugby when I worked there [fear of hyper-muscularity], there is a body consciousness around putting on muscle mass.'*

Although it appears that males and females respond to hypertrophy-focused training in a similar manner (Roberts, Nuckols, and Krieger 2020), females display lower levels (by ~45%) of skeletal muscle mass after puberty than males.(Hilton and Lundberg 2021). This results in differences in magnitude of increases in muscle mass and strength in absolute terms following resistance exercise training in males and females, despite similar relative increases in these outcomes (Roberts, Nuckols, and Krieger 2020). Additionally, increasing muscle mass through targeted interventions is a relatively slow process compared to other neuromuscular adaptations such as strength. For example, strength increases by 25%, on average, in females following 15 weeks of resistance exercise training, while muscle mass increases by ~3.3% (1.4 kg) in the same period (Hagstrom *et al.*, 2020). These concepts should be communicated to athletes who have fears of gaining what they perceive to be excessive quantities of muscle mass.

Interpersonal Approach

Seminal research on differences between males and females in communication suggested that males and females exist in linguistically distinct groups, with males being more active, aggressive, and task-orientated in their communication, as opposed to females, who tend to have an increased frequency of self-disclosure and expressiveness (Baird, 1976; Freed, 1996), although athlete-focused research in this area is equivocal (Sullivan, 2004). Three subthemes of interpersonal approach are presented: communication style, discussing female-specific issues, and professional boundaries/scope of practice.

Communication style

Overall, it was expressed by all coaches that they perceive their interpersonal engagement experienced with female athletes to differ in important ways from males, as exemplified by Coach 3 who remarked, *'they [females] will speak to you about how they are feeling, you know, so you have the interaction between you and a female athlete is a little bit better.'* This sentiment is shared and expanded upon by Coach 4 describing he/she *'do[es] find girls are a lot more loose in the sense of they have more fun in the weight room, like it's dancing, fun, partying, whereas guys is not to that same degree,'* which he/she stated leads to a differing interpersonal approach highlighted in their comment, '*it's just your coaching style just differs a bit between training the girls and the guys.'* Coach 5 expressed his/her belief that differences between males and females are present in motivational factors stating, *'Male athletes play well to feel good. And female athletes feel good to play well…you take that into your training session or coaching session as well. It's a different method of motivation, how you start interacting with the athletes.'*

Whether there are distinct differences between male and female athletes in communication styles has not been fully elucidated (Sullivan, 2004). However, all the coaches in this study described perceiving a need for divergence in communication and interpersonal approaches between male and female athletes. Given the general differences in psychosocial processes between the sexes, these arguably manifest in divergent interpersonal characteristics, and practitioners should be cognisant of this. Conversely, inter-individual variability, independent of sex, is likely sizable and must be acknowledged alongside between-sex differences, with further investigation warranted.

Discussing Menstrual Cycles

All coaches recognised the requirement to discuss issues around the menstrual cycle as a key difference in their practice compared to with male athletes. All coaches conveyed their willingness and comfort with discussing these issues with athletes, as demonstrated by Coach 3 who stated conversations of this nature are, '*part of my portfolio [discussing the menstrual cycle].'* Coach 3 emphasised that '*for them [the players] to be comfortable with me, I have to be comfortable with them,* *and they have to be open with me, they have to be honest and I don't make them feel insecure about it… [speaking directly to players] You all are mostly female here, I am the odd one out. So, by all means, if this is how you feel [experiencing symptomology of menstrual cycle]. Take a break, take some time.'* This sentiment was reiterated by Coach 8 who stated *'[I] felt it was really important that I did that [speak about the menstrual cycle] and didn't make a thing about it. So, I was real comfortable talking about it and stuff like that,'* while Coach 2 remarked that he/she '*could have a week where I'm chatting about it [the menstrual cycle] every day, but then I could have two weeks where it's not mentioned.'*

Coaches 5 and 7 suggested that the discussion of the menstrual cycle has become more prominent in their practice recently with Coach 5 noting '*it's become more a common conversation than it ever has in the past. So, in the past it was, whether it was, if the right word is taboo or not, it was not talked about in a public forum,'* and Coach 7 similarly remarking, *'[In the past] it was very something very personal and no, no discussion about that…Now it's very easy to speak about that.'*

The insights provided by the coaches relating to female-specific issues are arguably progressive, and should be welcomed by those advocating for increased awareness of female issues within sport (Mountjoy *et al.*, 2018). These calls for increased awareness may imply that there is a perception that discussing female-specific considerations such as the menstrual cycle with athletes is taboo, yet the viewpoint of the coaches in this study are in contrast to this perception, nor has it been the experience of the authors of the present study when working in their respective sports. Whether this perception of taboo relating to the menstrual cycle, which is regularly stated in academic (Prince and Annison, 2022; O'Loughlin, Reid and Sims, 2023), and mainstream domains (Ingle 2022) is a phenomenon strongly supported by empirical evidence, or is an artefact of a repeatedly-reinforced false narrative, remains to be determined.

Professional Boundaries and Scope of Practice

Six coaches (Coaches 2, 4, 5, 6, 7, and 8) expressed being aware of professional boundaries and scope of practice as aspects that they were more cognisant of with female athletes, particularly relating to aspects of female health:

At some points, I just don't think that's my lane to be having those kind of conversations [specific advice regarding menstrual dysfunction] with our female athletes when it's not something I've personally been through or couldn't fully understand other than what I've been told and read. (Coach 4)

[Regarding contraceptive use] I think that would have been probably advised by a senior doctor or someone like that, but it would have been way outside of my remit. (Coach 6)

Coach 8 noted that he/she had increased awareness and hesitancy to make physical contact with the female athletes:

That's probably one thing I didn't do with the girls, I'd probably be a little bit less hands on or ask for consent beforehand… that's one of the biggest ones in terms of style of delivery. That was the only thing that felt particularly different was like, you probably just grab a boy and move him. But I'd always have, literally the point I knew girls didn't mind, and they almost rolled her eyes every time I asked them, but I always wanted to have that option for it not to happen.

Coach 3 stated he/she does not currently systematically monitor menstrual cycle status as *'it's a personal thing…we can't just decide as a management to you know, we're going to monitor that,'* then proceeded to describe a previous decision to implement systematic pregnancy testing of players at a previous club-level team:

I don't know about [other team], what we decided was we said, look, because they're all female and it's a real thing [chance of pregnancy], you know, let's take pregnancy tests at the beginning of the season and then we'll take one every three weeks, and we had to get consent…But it's something that we decided as a management and we administered to the girls…So for me, as long as you have the ethics and the paperwork and the things behind it, I don't think you can't do it [pregnancy testing].

The coach described two primary motivations for implementing systematic pregnancy testing. First, to ensure athlete safety in the event of an unknown pregnancy:

If we, if they don't know that they are pregnant. And they play. There is a massive risk. Because the person can be six weeks pregnant and she doesn't know and she's takes a hit to the stomach, she gets severe pain. And she doesn't know why. And then what? Then does that fall on us? Does that fall on her? That's negligence from a medical point of view…

Second, to encourage safe-sex practices to improve player retention:

You know, they're going to be sexually active, same as the males, 18, 19, 20, 21 (age of players]…because they're girls, it doesn't mean they're not going to do it [engage in sexual activity]…I think it's very unfair [if players have an unplanned pregnancy] personally because, you lose good players if they are [pregnant], and you lose them for the amount of time as an ACL. It's nine months plus four, so you're looking at 13 months. That's if they come back in the shape that they were currently when they left. So, think about having some of your best players out with ACL injury because they weren't safe. And they are still young, you know, you might lose them through the system for years. That's happened to us many times.

A clear understanding of professional boundaries is imperative for safeguarding athletes. In multi-disciplinary teams, roles and scope of practice should be clearly defined and understood by all practitioners. Practitioners must be aware of and adhere to the limits of their scope of practice, yet scope of practice may not be well defined by governing bodies. Unions must actively engage with practitioners to ensure that they are fully educated in athlete welfare and safeguarding responsibilities, and stringently adhere to the principles of best practice in this area.

Study Strengths and Limitations

These coaches provided insight into their experience and perceptions of differences between males and females in athlete engagement with physical preparation programs and interpersonal interactions. The position held and the experience of the coaches is a clear strength of this study, although employment status is not necessarily a good indicator of expertise or knowledge. Nonetheless, to our knowledge, this is one of the first studies to investigate attitudes, beliefs, and practices in elite-level strength coaches regarding male and female differences, and as such, illustrates the current understanding and opinions of S&C practitioners in international level women's rugby union. The qualitative methods employed in this study allowed for systematic analysis of rich information.

Although the elite status of coaches is considered a strength of this study, it could also be viewed as a limitation. The homogeneity in the status of the coaches should lead to caution in interpreting and applying the results to practitioners in rugby as a whole. The viewpoints expressed may not be similar to those held by sub-elite coaches, those working with amateur athletic populations, or those within other sports. The merit of occupying a senior position in an elite team should not be assumed *de facto* to reflect a high level of competency and knowledge. In addition, three-quarters of the coaches interviewed were male, and while this is representative of the current landscape at the international level, the majority of coaches arguably present an androcentric view of beliefs and attitudes towards conditioning practices in women's rugby union i.e., adopting practices from, and consistent comparisons to the male game.

Conclusions

This study provides important insights and contextual evidence for the understanding of male and female differences in the interpersonal relationships of female rugby players from the perspective of elite-level strength coaches, which, to date, has not been explored. Differences in psychosocial factors, such as communication and social dynamics characteristics, may lead to different barriers to engagement when comparing male and female athletes. Understanding these nuances and how to effectively engage with athletes to overcome these perceived barriers are central functions of the coach. Practitioners should not assume that players possess tacit knowledge pertaining to physical preparation, and must effectively communicate task-specific requirements and the relevant dynamic correspondence of the physical preparation strategy.

Although the evidence relating to differences between male and female athletes in interpersonal approach is conflicting, and high degrees of individual variability are present, the coaches in this study consistently perceived distinct differences between male and female rugby players. Practitioners should be aware of these potential differences, with further research required to determine what constitutes effective communication strategies to ensure that successful relationships are developed with athletes. Practitioners should be highly cognisant of professional boundaries and place athlete welfare as paramount at all times.

The previous chapter showed that discussing female-specific issues relating to menstruation and hormonal contraceptive use are viewed by coaches as key and unique aspects of coaching female athletes. However, despite coaches reporting the importance of these issues, previous chapters have shown insufficient knowledge and support structures for monitoring these factors. Several coaches reported that they do not currently have effective athlete monitoring systems related to the menstrual cycle and often lack any awareness of the potential influence of hormonal contraceptives. The potential influence of the menstrual cycle and/or hormonal contraceptives on performance, adaptation, and injury risk has been the subject of much academic and public discourse in recent years. Understanding the effects of these unique aspects of female athlete physiology may aid practitioners in improving the efficacy of athletic development programs for female athletes.

The prevalence of hormonal contraceptive use in female rugby athletes is largely unknown, and much of the literature in this area focuses on endurance-based sports. The following chapter reports data from a survey-based study which explored hormonal contraceptive use and menstrual cycle-related symptomology in rugby and powerlifting female athletes. Rugby athletes were viewed as "strength and power" athletes, while powerlifting athletes were viewed as solely "strength" athletes and allowed for exploration of potential differences between the cohorts.

The chapter will first discuss the key definitions relating to the menstrual cycle and hormonal contraceptives before briefly exploring how these factors may influence athletic performance and summarising previous relevant literature. The chapter will then explain the methodology used and report that hormonal contraceptive use and negative symptomology rates did not differ between the cohorts. This chapter will clearly demonstrate that a high proportion of rugby athletes use hormonal contraceptives, with the oral contraceptive pill being the most commonly used form. I will also show that a high proportion of hormonal contraceptive users and non-users experience negative symptomology associated with hormonal contraceptive use and menstrual cycle, respectively. I will argue that the data presented in this chapter highlight the importance for athletes and coaches to have an open dialogue regarding menstrual cycle function and hormonal contraceptive use, and that coaches adopt an accommodating culture in which flexibility may be permitted to accommodate for those athletes experiencing severe symptoms of the menstrual cycle or hormonal contraceptive use.

Chapter 4 – Study 3

Prevalence of hormonal contraceptive use and reported side effects of the menstrual cycle and hormonal contraceptive use in powerlifting and rugby.

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Abstract

Objectives:

The prevalence of hormonal contraceptive (HC) use and the associated symptomology of use or non-use are under-studied in athletic populations, and in particular, in strength and collision sports. This study aimed to investigate the prevalence of hormonal contraceptive use and reported side effects of the menstrual cycle and hormonal contraceptive use in powerlifters and rugby players.

Methods:

Competitive female powerlifters and rugby players (aged ≥18 y), representing a strength and a collision sport respectively, completed an anonymous online questionnaire for the purpose of assessing self-reported prevalence of HC use, and symptoms of the menstrual cycle and HC use. Athletes were categorized by sport (powerlifters, n=149; rugby players, n=135) in order to conduct a stratified analysis. For open-ended questions, a content analysis was conducted to categorize responses, and frequency analyses were performed.

Results:

Current HC use was reported by 51.1% of athletes, with similar prevalence for the two sports (powerlifting, 48.3% vs. rugby, 54.1%, *P*=0.34). Side effects of the menstrual cycle were reported in 83.5% of non-HC users, with the most common being unspecified cramping (42.4%), headache/migraine (24.5%), and fatigue (24.5%). Side effects were reported in 40.0% of HC users, with the most common being mood changes (17.9%), stomach pain (8.3%) and headaches/migraines (6.9%).

Conclusion:

A large proportion of HC users and non-users in this study experience negative side effects of HC use and the menstrual cycle, respectively. The symptoms experienced by both groups are wide-ranging, with a high degree of variation between individuals. The negative side-effects experienced by HC users and non-users may have an influence on athletic performance, and this requires future investigation.

Keywords:

menstruation ; collision sports; female; pain; strength sports;

Introduction

The menstrual cycle is an important biological process that occurs between menarche (first menstrual cycle and bleeding) and menopause (permanent cessation of the menstrual cycle), and is characterized in eumenorrheic women by a significant, measurable cyclical variation of endogenous sex hormones, namely estrogen and progesterone (Stricker *et al.*, 2006). Notably, the shifting hormonal milieu experienced by eumenorrheic women may influence athletic performance at different stages of the menstrual cycle (Blagrove, Bruinvels and Pedlar, 2020; McNulty *et al.*, 2020). A large proportion of eumenorrheic women experience negative side-effects and symptoms associated with these hormonal fluctuations at different phases of the menstrual cycle (Bruinvels *et al.*, 2016, 2020; Martin *et al.*, 2018b), with a large proportion of athletes (i.e., 50.0% to 84.6%) perceiving the menstrual cycle to have a direct negative effect on their performance in training and competition (Findlay *et al.*, 2020; Carmichael *et al.*, 2021).

Hormonal contraceptives (HCs) are exogenous hormones which affect the endocrine regulation of the female reproductive system and may inhibit ovulation (De Leo *et al.*, 2016; Elliott-Sale and Hicks, 2018). HC users display a hormonal profile of consistently low endogenous sex hormone concentrations, which induces amenorrhea (Jain and Wotring, 2016). HCs are administered by a variety of delivery methods, with oral contraceptives (OC) being the most common delivery method in both general population and athletic cohorts (Cea-Soriano *et al.*, 2014; Daniels, Daugherty and Jones, 2014; Martin *et al.*, 2018b; Schaumberg *et al.*, 2018). HCs are also classified by the hormones employed; combined HCs having both a progestin and estrogenic component, while other HCs having a progestin only component. The differing profiles of HCs may produce variations in their physiological effects and subsequent side-effects, and therefore, may differ in their potential influence on athletic performance (Elliott-Sale *et al.*, 2020). There is equivocal evidence regarding the influence of hormonal contraceptives on exercise performance and chronic training adaptations, with studies reporting HC-use having a positive, negative and neutral influence on adaptation to resistance training (Ruzić, Matković and Leko, 2003b; Ihalainen, Hackney and Taipale, 2019; Thompson *et al.*, 2020; Bozzini *et al.*, 2021; Myllyaho *et al.*, 2021; Umlauff *et al.*, 2021).

Although menstrual function is acknowledged as a critical element of female athlete health, there is a sparsity of research examining the symptomology of the menstrual cycle and prevalence of HC use in athletic populations (Elliott-Sale *et al.*, 2020; McNulty *et al.*, 2020). Prevalence of HC use has been reported to be higher in athletic populations (40.2% to 49.5%) than in the general population (27.0% to 46.0%) (Torstveit and Sundgot-Borgen, 2005; Cea-Soriano *et al.*, 2014). The higher prevalence of HC use in athletic populations may be due to the use of HC to minimize the perceived negative side-effects of the menstrual cycle and to control menstruation (Martin *et al.*, 2018b; Schaumberg *et al.*, 2018; Clarke *et al.*, 2021). For example, one recent study in elite athletes has shown HC users to experience fewer negative side-effects compared to non-HC users (Martin *et al.*, 2018b).

The limited research to date on the symptomology of the menstrual cycle and prevalence of HC use in athletic populations has primarily focused on endurance athletes and non-collision team sports. Few data exist for strength or collision sports. The nature of these sports is unique as the physiological determinants and demands of performance differ greatly to that of sports previously researched. Whether chronic resistance training, or repeated collisions to the torso influence perceived symptomology is yet to be investigated. Therefore, this study investigated prevalence of HC use and the symptomology of the menstrual cycle or HC use specifically in powerlifting and rugby, as they are representative of sports where the practice of resistance training is highly utilized and attainment of high levels of maximal strength are viewed as key performance indicators, but differ in the presence, or lack of collisions.

Methods

Experimental approach to the problem

Competitive female powerlifters or rugby players (aged ≥18 y) completed an anonymous online questionnaire through a link shared via professional networks and social media platforms using a questionnaire previously established for the purpose of assessing self-reported symptomology of the menstrual cycle and HC use (Martin *et al.*, 2018b). The questionnaire was recreated in Google Forms and was open for three weeks beginning October 19th, 2020.

Subjects

The study was approved by the Research Ethics Committee at the ANONYMISED, Ireland (permit: ANONYMISED), in accordance with the Declaration of Helsinki. Subjects provided informed consent through a tick box option in order to proceed to the questionnaire. A convenience sample of 286 athletes accepted the study invitation and completed the survey, with 284 responses included in the final analysis (Figure 4). Inclusion criteria were that subjects had to self-report as being i) a biological female, ii) aged ≥18 y, iii) pre-menopausal, and iv) actively competing in the sport of either powerlifting or rugby.

Data analysis

Statistical analyses were performed using SPSS (Version 24.0, IBM Corp., Armonk, NY). To prevent duplicate data, the database was searched for non-unique dates of births and identical values were visually checked to assess whether the responses were different. Descriptive statistics (i.e., mean, SD, and frequency analysis) were used to display subject characteristics and responses to survey questions providing ordinal data. Athletes were categorized by their sport (powerlifter or rugby player) in order to conduct a stratified analysis. For open-ended questions, a content analysis was conducted to categorize responses, and a frequency analysis performed. Assumptions of normality were checked using the Kolmogorov-Smirnov test. Between-group differences were examined using independent sample t-tests. Pearson's chi-squared (X^2) tests were used to examine the relationship between categorical variables, with Fisher's exact tests used where <80% of expected cell counts were >5 (Queen, Quinn and Keough, 2002). Duplicate responses were identified via visual inspection and removed. Data are represented as mean±SD, frequencies and percentages, and the threshold for statistical significance was set at $p \leq 0.05$.

Results

Subjects and prevalence of HC use

Subject characteristics are detailed in Table 2. HC users were significantly older than non-HC users (28.12±7.27 vs. 25.83±5.92 y; P=0.004). Rugby players commenced training (17.39±6.10 vs. 24.78±6.84 y; $P \leq 0.001$) and competing (18.45±5.42 vs. 25.62±6.90 y; $P \leq 0.001$)) in their chosen sport at a significantly younger age that the powerlifters. Subjects consisted predominantly of Europeans (65.8%) and North Americans (19.0%), respectively. The rugby cohort consisted of varying competitive statues ranging from International/National (25.2%) and provincial/club (74.8%), respectively.

An approximately even split between sports was reported [powerlifting, n=149 (52.5%); rugby, n=135 (47.5%)]. One hundred and forty-five (51.1%) athletes reported being a current HC user, with the remaining 48.9% not currently using any form of HC, although 4.0% of which were using non-hormonal intrauterine devices (Figure 4). Participation in either sport did not influence HC use (X^2_1=0.9, P=0.34) with similar prevalence between the two groups observed as 48.3% and 54.1% in powerlifting and rugby, respectively.

Table 2. Subject Characteristics

	Whole Cohort			Rugby Cohort			Powerlifting Cohort		
	Total (n=284)	Non-HC Users (n=139)	HC Users (n=145)	Total (n=135)	Non-HC Users (n=62)	HC Users (n=73)	Total (n=149)	Non-HC Users (n=77)	HC Users (n=72)
Age (y)	26.95±6.70	28.12±7.27	25.83±5.92*	25.32±5.94†	25.84±6.49	24.88±5.44	28.43±7.02	29.96±7.39	26.79±6.25
Height (m)	1.65± 0.08	1.65±0.09	1.66±0.07	1.66±0.09†	1.66±0.11	1.67±0.07	1.64±0.07	1.64±0.07	1.64±0.07
Body mass (kg)	72.86±16.99	73.58±17.52	74.12±16.52	75.67±15.79	75.94±16.56	75.44±15.22	72.22±17.90	71.69±18.14	72.79±17.74
Age began training (y)	21.26±7.47	22.82±7.97	19.77±6.64*	17.39±6.10†	18.73±7.07	16.25±4.90*	24.78±6.84	26.12±7.11	23.35±6.28*
Age began competing (y)	22.21±7.18	23.96±7.37	20.53±6.60*	18.45±5.41†	20.24±5.87	16.93±4.51*	25.62±6.90	29.96±7.11	24.18±6.39*
Weekly training duration (h)	7.62±3.52	7.80±3.54	7.44±3.52	5.8±2.97†	5.66±2.48	5.92±3.34	9.26±3.17	9.52±3.33	8.99±2.99

*indicates a significant difference between hormonal contraceptive (HC) user and non-HC users within the indicated cohort (p≤0.05); †indicates a significant difference between rugby and powerlifting for "Total" column (P≤0.05).

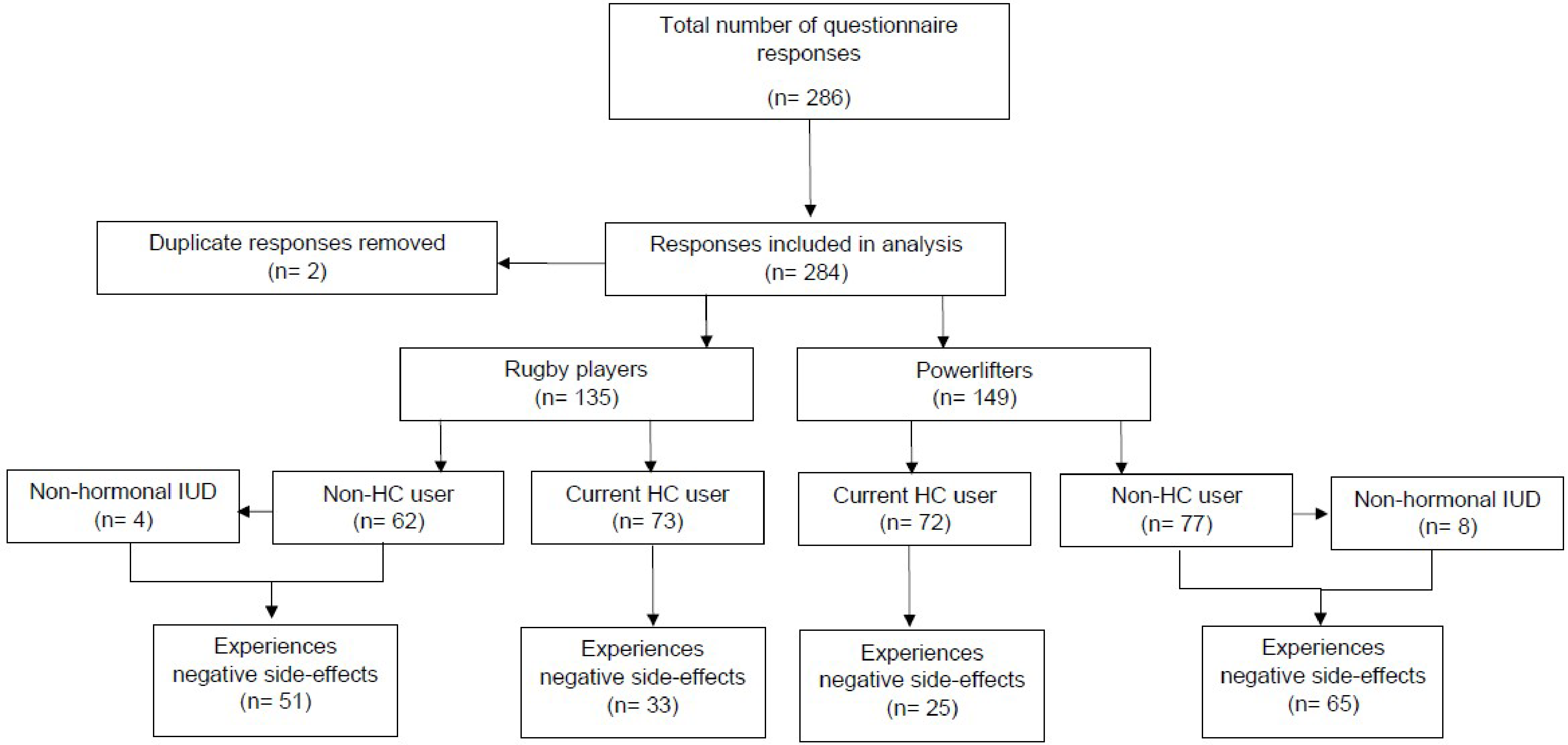

Figure 4. The prevalence of hormonal contraceptive (HC) use and perceived negative side-effects of the menstrual cycle and HC use. IUD, intrauterine device.

Menstrual cycle (non-HC users)

83.5% of non-HC users reported side effects of the menstrual cycle (Table 3), with the most common being unspecified cramping (42.4%), headache/migraine (24.5%), and fatigue (24.5%). 6.5% of non-HC users described themselves as amenorrhoeic (defined as having missed more than three consecutive periods). The average menstrual cycle length for the remaining athletes was 29.2±3.3 d, with 69.1% of athletes reporting their menstrual cycle as variable in length. 18.0% and 13.7% of athletes described themselves as having menorrhagia (defined as abnormally heavy bleeding during their period) and being oligomenorrheic (defined as a menstrual cycle length of greater than 35 days), respectively.

Chi-square analysis revealed significant differences between sports for prevalence of unspecified cramp (powerlifting, 33.8% vs. rugby, 53.2%; X^2_1=5.3, P=0.016), and abdominal pain (powerlifting, 18.2% vs. rugby, 6.5%; X^2_1=4.2, P=0.034). No other differences were found between the sports in reported side effects or symptomology of the menstrual cycle (all P>0.05).

Table 3. Frequency analysis of side effects in non-hormonal contraceptive users (n=139)

Symptom	**Frequency**	**Prevalence (%)**
Unspecified cramp	59	42.4
Headache / migraine	34	24.5
Tiredness / fatigue / lethargy	34	24.5
Mood Changes	25	18.0
Back pain	22	15.8
Stomach pain / abdominal cramps	18	12.9
Bloating	14	10.1
Nausea / sickness /vomiting	12	8.6
Sore breasts	11	7.9
Irritability	10	7.2

Increased appetite	7	5.0
Unspecified pain	6	4.3
Diarrhea / digestive issues	6	4.3
Poor skin	5	3.6
Sleep disturbances	5	3.6
Hot flushes / increased sweating	4	2.9
Decreased appetite	4	2.9
Dizzy / lightheaded / lack of coordination	3	2.2
Muscle ache	3	2.2
Weakness	3	2.2
Leg discomfort	2	1.4
Constipation	2	1.4
Problems with exercise	2	1.4
Flustered / lack of focus	2	1.4
Pre-menstrual syndrome	2	1.4
Heavy bleeding	1	0.7
Increased heart rate	1	0.7
Vaginal pain	1	0.7
Shortness of breath	1	0.7
Colic	1	0.7
Cold chills	1	0.7
Excessive salivating	1	0.7
Weight gain	1	0.7
Increased libido	1	0.7
Increased energy	1	0.7

Water retention	1	0.7
Excessive thirst	1	0.7
Increased night-time urination	1	0.7

HC Use

40.0% of HC users reported side effects of HC use (Table 4), with the most common being mood changes (17.9%), abdominal pain (8.3%) and headaches/migraines (6.9%). The most prevalent form of HC delivery reported were oral contraceptives (55.2% of HC users). Length of use ranged from ≤6 months (n=5) to ≥5 years (n=41). 30.0% of oral HC users reported never engaging in the 7 "pill-free" days each cycle, while 45.0% reported always observing the 7 "pill-free" days.

Chi-square analysis revealed a significant difference between sports for prevalence of mood changes (powerlifting, 11.1% vs. rugby, 24.7%; X^2_1=4.5, P=0.027). No other differences were found between the sports in reported side effects or symptomology of HC use (all p>0.05).

Table 4. Frequency Analysis of Side Effects in Hormonal Contraceptive Users (n=145)

Symptom	**Frequency**	**Prevalence (%)**
Mood changes	26	17.9
Stomach pain	12	8.3
Headaches / migraines	10	6.9
Poor skin	8	5.5
Tiredness / fatigue / lethargy	8	5.5
Bloating	7	4.8
Weight gain	6	4.1
Breast Issues (swollen or sore)	5	3.4

Spotting	5	3.4
Irregular period	4	2.8
Loss of period	4	2.8
Negative effect on performance	4	2.8
Nausea / sickness / vomiting	2	1.4
Water retention	2	1.4
Increased appetite	2	1.4
Back pain	2	1.4
Heavier period	2	1.4
Decreased appetite	2	1.4
Reduced libido	2	1.4
Altered cycle length	1	0.7
Painful period	1	0.7
Pre-menstrual syndrome	1	0.7
Dizziness	1	0.7
Increased libido	1	0.7
Lighter bleeding / period	1	0.7

Discussion

This investigation of the symptomology of the menstrual cycle and prevalence of HC use in athletic populations is the largest to date in a rugby cohort, and the only study in powerlifters. This study thereby provides new data for sports with a considerable demand for strength and power components, and additionally those with collision events. Approximately half of the female athletes in this study were current HC users, and participation in powerlifting or rugby did not result in a difference in prevalence of use. HC users and non-HC users alike experienced varying degrees of negative side-effects of HC use and of the menstrual cycle, with side effects being greater in non-HC users regardless of sport.

The prevalence of HC use of 51.1 % in this athlete cohort is higher than that previously reported for the general population, which varies in the reported prevalence of use (21.2% to 46.0%) (Brynhildsen *et al.*, 1997; Cea-Soriano *et al.*, 2014; Daniels, Daugherty and Jones, 2014), and is similar to the prevalence of 49.5% recently reported in elite female athletes from a range of sports (Martin *et al.*, 2018b). As previously stated, the greater prevalence of HC use in athletic populations may be due partly to the perception by athletes that they can better predict and control menstruation, and attempting to avoid menstruation during periods of competition or training of heightened importance (Martin *et al.*, 2018b; Schaumberg *et al.*, 2018). An important related point, especially given the high prevalence of HC use in athletes, is that many athletes equate the withdrawal bleed experienced during the "pill-free" days of HC use with a menstrual bleed. This confusion may lead to athletes and coaches alike assuming an athlete is eumenorrheic when HC use may be masking menstrual dysfunction (Forsyth and Roberts, 2018). Given that menstrual dysfunction is an important indicator of Relative Energy Deficiency in Sport (RED-S) (Mountjoy *et al.*, 2018), and the recent call for positive communication around the menstrual cycle in this context (Ackerman *et al.*, 2020; Heather *et al.*, 2021), increasing awareness of this issue of 'masking' may be important amongst athletes and practitioners.

A large proportion (83.5%) of non-HC users experienced negative side-effects of the menstrual cycle with the most cited symptoms being cramping, headache/migraine and fatigue. Athlete type (powerlifter vs. rugby player) had an influence on the reported symptoms, with rugby players reporting higher incidence of "*unspecified cramp*" (53.2% vs. 33.8%), and powerlifters reporting higher incidence of "*abdominal cramp*" 18.2% vs. 6.5%). Presently, we attribute this finding as an artefact of the terminology of the questionnaire coupled with the content analysis employed. When an athlete reported cramp as a symptom but did not directly state it as an abdominal cramp, it was categorized as "*unspecified cramp*". When the respective data for "*unspecified cramp*" and "*abdominal cramp*" are combined for each sport, there is no difference between sports. The prevalence of reported negative side-effects of the menstrual cycle in non-HC users are similar to those previously reported (74 to 93%)

(Martin *et al.*, 2018b; Bruinvels *et al.*, 2020; Findlay *et al.*, 2020; Parker *et al.*, 2021), indicating that the focus on strength training, with or without the presence of collision events, in these sports does not have a unique influence on symptom prevalence for the menstrual cycle.

HC users had lower prevalence of negative side-effects (40.0%) of HC use, when compared with symptom prevalence for the menstrual cycle in non-HC users in this study. The most common reported side-effect of HC use was mood changes (e.g., increased anxiety, depressive symptoms, or increased irritability). With 17.9% of HC users reporting this symptom, this is almost identical to the prevalence of the same symptom in the non-HC users (18.0%). Athlete type was shown to have a significant influence on mood changes, with the 24.7% incidence in rugby players being higher than the 11.1% in powerlifters. A physiological basis to explain this finding is lacking at present, but a speculative explanation may be that the individual versus team-based nature of the respective sports could influence the athlete's awareness and perception of this symptom. Alternatively, this may be an incidental finding.

The data presented in this study highlight the importance for athletes and coaches to have an open dialogue regarding menstrual cycle function and HC use. Both HC and non-HC users experience negative side-effects, which may have an influence on performance in training and competition (Brisbine *et al.*, 2020; Elliott-Sale *et al.*, 2020; Findlay *et al.*, 2020; McNulty *et al.*, 2020). We recommend that coaches adopt an accommodating culture in which flexibility may be permitted to accommodate for those athletes experiencing severe symptoms of the menstrual cycle or HC use.

This study collected responses representing a wide, geographical spread, but a limitation is that we did not record the ethnicity of the respondents. Whether ethnicity influences the physiological response to, and symptoms perceived by HC and non-HC using athletes is yet to be investigated. Another limitation of this study is that specific details relating to contraceptive use i.e., type of OC, brand name, progestins used etc. were not collected. Future studies should also consider the effects of the length of use of HCs on aspects of health, training and performance, as 28.2% of HC users in this study have used HC continually for ≥5 years. These long-term implications are not yet understood and are particularly important given that a third of respondents in this study do not follow common practice guidelines for HC use by observing the monthly "*pill-free*" time period.

In conclusion, approximately half of the athletes in this study used HCs, and a large proportion of HC users and non-users experience negative side-effects of HC use, and of the menstrual cycle, respectively. The symptomology experienced by HC and non-HC users is wide-ranging, with a high degree of variation between individuals, but prevalence in these strength and collision sport athletes is broadly consistent with that reported in other athletes.

In the previous chapters, we showed that practitioners in women's rugby tend to adopt an androcentric-informed approach to coaching methodologies. Arguably, coaches adopt this view due to the dearth of relevant literature pertaining to the physical preparation of female rugby athletes. Previous chapters have shown that coaches perceive there to be little women's rugby focused on empirical research for them to draw inferences to their own practices. One key research gap highlighted by coaches is related to the physical match demands of women's rugby union, with few studies examining this aspect. Data describing the physical match characteristics of men's rugby can be easily sourced, yet how well these data can inform practices in the female code is unknown.

In the following chapter I will report the data from a three-year longitudinal analysis of the physical match characteristics of an international women's rugby union team competing in the Six Nations Tournament

The chapter will begin by discussing the relevant literature relating to the physical match characteristics of women's rugby union, arguing that a large research gap exists in this area. The chapter will then discuss the methodology used and show that position has a significant effect on the majority of physical match characteristics reported. I then discuss some of the key contextual factors that must be considered in the interpretation of these data. I will also highlight some fundamental limitations in this area of research, that is, the application of GPS-derived data. Finally, the chapter reports that the total running demands were similar to those previously reported in other international cohorts employing a similar methodology. I propose that training methodologies for elite female rugby union players should consider the unique demands across positional groups, with specific consideration of high velocity running and collision frequency.

Chapter 5 – Study 4

Physical Match Demands of International Women's Rugby Union: A Three-Year Longitudinal Analysis of a Team Competing in The Women's Six Nations Championship

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Abstract:

There is a paucity of studies describing the physical match demands of elite international women's rugby union, which limits coaches' ability to effectively prepare players for the physical demands required to compete at the elite level. Global positioning system technologies were used to measure the physical match demands of 53 international female rugby union players during three consecutive Women's Six Nations Championships (2020–2022), resulting in 260 individual match performances. Mixed-linear modelling was used to investigate differences in physical match demands between positions. Significant effects ($p < 0.05$) of the position were observed for all variables, with the exception of relative distances ($m \cdot min^{-1}$) at velocities of 1.01–3.00 $m \cdot s^{-1}$ ($p = 0.094$) and 3.01–5.00 $m \cdot s^{-1}$ ($p = 0.216$). This study provides valuable data on the physical match demands of elite international women's rugby union match play that may aid practitioners in the physical preparation of players to compete at this level. Training methodologies for elite-level female rugby union players should consider the unique demands across positional groups with specific considerations of high-velocity running and collision frequency.

Introduction

The women's rugby union has experienced significant growth in participation numbers in recent years, with approximately 1 million active players registered globally in 2021 (*World Rugby Year In Review 2021*, no date). Despite this growth and the professionalization of the male game that began almost three decades ago, the majority of "elite" (international-level) female players in the modern era have participated as amateurs ('Women's Survey: Who's Playing the Game?', 2018). The Women's Six Nations, existing in its current format since 2002, is an annual international rugby union competition contested among six top-ranked European teams i.e., England, France, Ireland, Italy, Scotland, and Wales (*About Six Nations Rugby*, no date). From 2016 onwards, the decision by specific nations to provide professional contracts to their international players has resulted in the Women's Six Nations Championship simultaneously consisting of professional, semiprofessional, and amateur teams.

Rugby union can be described as an invasion field-based team sport consisting of intermittent bouts of high-intensity efforts i.e., running, sprinting, tackling, rucking, mauling, and scrummaging, and periods of lower-intensity activity i.e., walking, jogging, and resting (Coughlan *et al.*, 2011). The improved sophistication and increased use of global positioning systems (GPS) technology in rugby union has enabled the in-depth analysis of the physical demands of match play (Cahill *et al.*, 2013; Cunningham *et al.*, 2016), i.e., running distances, velocities, accelerations, decelerations, and related variables. Modern GPS technology also provides valid measures of collision events in rugby union (MacLeod *et al.*, 2018). These data may provide practitioners with useful metrics regarding physical match demands and monitoring training load, thereby aiding in the design of appropriate physical conditioning programs to improve tolerance to the demands of match play, potentially improving performance and reducing injury risk (Foster, Rodriguez-Marroyo and de Koning, 2017; McLaren *et al.*, 2018). The match demands of men's rugby union are well-documented across both playing level (Austin, Gabbett and Jenkins, 2011, p. 14; Coughlan *et al.*, 2011; Read *et al.*, 2017) and age grades (Bridgeman and Gill, 2021). A paucity of studies describing match demands of women's rugby union exists (Heyward *et al.*, 2021), particularly at the international level, with previous studies using lower-ranked teams and small samples (Suarez-Arrones *et al.*, 2014; Sheppy *et al.*, 2020). The most comprehensive analysis of the physical demands of women's international rugby union to date reported differences between playing positions in high-velocity running (>5.5 $m \cdot s^{-1}$), accelerations, decelerations, and collisions (Woodhouse *et al.*, 2021a). Notably, this cohort ranked in the top 2 teams globally for the entirety of the data collection period, with several years consisting of professional players. The inclusion of data from professional players may limit the extrapolation of these findings to the wider international women's rugby union population, as the majority of players are amateur. The heterogeneity of the methodology employed in previous studies of international cohorts (Suarez-Arrones *et al.*, 2014; Sheppy *et al.*, 2020; Woodhouse *et al.*, 2021a), specifically the inclusion/exclusion criteria for match files and the used velocity thresholds, limit further comparison and synthesis of the existing literature.

This study provides the three-year longitudinal analysis of physical match demands of an elite, amateur, women's international rugby union team competing in the Women's Six Nations Championship. The study also investigates the influence of playing position, which was hypothesized to have a significant effect on physical match demands.

Materials and Methods

Following institutional ethical approval (REF: DCUREC/2022/012), a three-year longitudinal analysis of the physical match demands of the Women's Six Nations Championship was conducted between 2020 and 2022 inclusive. A total of 53 players from a single team generated 260 match files from 12 matches (mean individual match files: 3.9 ± 2.6; median: 3; range: 1–12) across the three successive campaigns. Individual positions were categorized into seven groups: front-row (FR; n = 11, prop and hooker), second-row (2R, n = 7), back-row (BR; n = 9, flanker and number eight), scrum-half (SH, n = 5), fly-half (FH, n = 5), center (C, n = 5), back-three (B3; n = 11, winger and full-back).

All matches took place between the hours of 12:00 and 22:00. Physical match demands were quantified using APEX GPS units (STATSports Apex; STATSports, Newry, Ireland), which were switched on and fitted at least 15 min prior to the start of match play which is recommended to improve connectivity (Scott, Scott and Kelly, 2016). These devices demonstrate typical measurement error of

<5% in coefficient of variation (CV), with close (<2% CV) comparisons to sport-specific variable measurements i.e., distance covered and peak velocity (Beato *et al.*, 2018; Beato and de Keijzer, 2019). Files were downloaded into the manufacturer's software for analysis, with warm-up and half-time periods removed post hoc. All GPS files were included in the analysis, regardless of time on pitch (mean: 69.23 ± 32.49 min; median: 77.97 min; range: 1.75–123.48 min).

The analyzed variables were total distance, distances covered at <1.00, 1.01–3, 3.01–5.00, 5.01–5.50, and >5.50 $m \cdot s^{-1}$. Total collisions (contacts >8 g) were also recorded. Maximal velocity was determined via a 40 m sprint test conducted in the preseason periods using the SmartSpeed single-beam timing gates system (VALD, Brisbane, Australia). Average velocity achieved from the 30–40 m split was computed as the maximal velocity and manually imported to the manufacturer's software. Maximal velocity was automatically increased by the manufacturer's software in the event of an individual achieving velocities greater than those assigned on three subsequent occasions during match play, with the average of these three higher velocities becoming the updated maximal velocity. Acceleration and deceleration metrics were recorded, but not included in the final analysis due to high levels of error for these specific metrics (Thornton *et al.*, 2019). All variables are expressed in absolute terms (m) and relative to playing time ($m \cdot min^{-1}$). Arbitrary thresholds were set to align with, and allow for comparison, where possible, to previous studies on female rugby (Suarez-Arrones *et al.*, 2014; Bradley *et al.*, 2020; Sheppy *et al.*, 2020; Callanan, Rankin and Fitzpatrick, 2021; Woodhouse *et al.*, 2021a).

Statistical analysis was completed using the Statistical Package for the Social Sciences SPSS v.27, IBM, Chicago, IL, USA). Data are presented as mean ± standard deviation (SD) unless otherwise stated. All variables were log transformed prior to statistical analysis. Differences in the relative physical demands between playing positions were examined using a series of linear mixed models. Playing seasons (2020, 2021, and 2022) and position were treated as the fixed effects, and individual players were treated as a random effect. Significant fixed effects were probed using post hoc Bonferroni comparisons. Due to variations in minutes played across positions and matches, statistical analysis was only performed on data for relative to playing time ($m \cdot min^{-1}$), but not absolute distances (m). All statistical analyses accepted significance at $p < 0.05$.

Results

Physical match demands are reported in Tables 5–7. The pairwise comparisons of relative physical match demands separated by playing position are shown in Table 7. Significant effects of the position were observed for all variables, with the exception of relative distances at velocities of 1.01–3.00 and 3.01–5.00 m·s^{-1}.

Table 5. Physical match demands of match play for a squad of international female rugby union players during three consecutive years of the Women's Six Nations Championship.

Variable	**Mean**
Time played	69.2 ± 32.5
Total distance (m)	4177 ± 2066
Relative distance (m·min^{-1})	59.6 ± 8.68
Peak velocity achieved (m·s^{-1})	6.76 ± 0.97
Percentage of maximum velocity achieved (%)	85.7 ± 8.95
Total distance < 1 m·s^{-1} (m)	741 ± 378
Relative distance < 1 m·s^{-1} (m·min^{-1})	10.6 ± 1.70
Total distance at 1.01–3.00 m·s^{-1} (m)	2076 ± 1036
Relative distance at 1.01–3.00 m·s^{-1} (m·min^{-1})	29.5 ± 4.53
Total distance at 3.01–5.00 m·s^{-1} (m)	1157 ± 637
Relative distance at 3.01–5.00 m·s^{-1} (m·min^{-1})	16.6 ± 5.80
Total distance at 5.01–5.50 m·s^{-1} (m)	97.0 ± 75.8
Relative distance at 5.01–5.50 m·s^{-1} (m·min^{-1})	1.40 ± 0.89
Total distance at > 5.50 m·s^{-1} (m)	106 ± 126
Relative distance at > 5.50 m·s^{-1} (m·min^{-1})	1.51 ± 1.71
Total collisions (n)	31.6 ± 39.3
Collisions per min	0.46 ± 0.48

Table 6. Positional differences in the absolute physical match demands of match play for a squad of international female rugby union players during three consecutive years of the Women's Six Nations Championship.

	FR (n = 62)	**2R (n = 35)**	**BR (n = 47)**	**SH (n = 28)**	**FH (n = 13)**	**C (n = 28)**	**B3 (n = 47)**
Time played (min)	58.1 ± 31.8	74.7 ± 28.6	73.2 ± 33.2	56.2 ± 33.3	63.6 ± 33.9	77.8 ± 35.2	80.2 ± 27.0
Total distance (m)	3232 ± 1812	4490 ± 1779	4118 ± 1967	3541 ± 2203	4231 ± 2362	4917 ± 2219	5173 ± 1842
Total distance < 1 m·s^{-1} (m)	542.0 ± 294	731 ± 282	849 ± 414	564 ± 350	725 ± 392	887 ± 408	925 ± 345

Total distance at 1.01–3.00 m·s^{-1} (m)	1740 ± 987	2197 ± 905	2086 ± 1045	1709 ± 1108	2032 ± 1095	2434 ± 1114	2438 ± 912
Total distance at 3.01–5.00 m·s^{-1} (m)	863 ± 579	1432 ± 619	1057 ± 510	1100 ± 754	1213 ± 759	1306 ± 614	1367 ± 588
Total distance at 5.01–5.50 m·s^{-1} (m)	50.3 ± 54.7	80.4 ± 64.0	75.3 ± 50.0	92.4 ± 73.1	136 ± 91.7	133 ± 68.0	163 ± 74.3
Total distance at > 5.50 m·s^{-1} (m)	36.1 ± 57.6	49.8 ± 48.8	49.7 ± 44.5	75.5 ± 73.2	125 ± 96.7	158 ± 118	280 ± 149
Total collisions (n)	24.7 ± 29.2	24.0 ± 28.1	67.6 ± 56.0	20.1 ± 29.6	17.2 ± 25.7	26.3 ± 29.5	24.2 ± 31.8

FR = front row, 2R = second row, BR = back row, SH = scrum half, FH = fly half, C = center, B3 = back three.

Table 7. Positional differences with pairwise comparisons in the relative physical match demands of match play for a squad of international female rugby union players during three consecutive years of the Women's Six Nations Championship.

	FR (n = 62)	**2R (n = 35)**	**BR (n = 47)**	**SH (n = 28)**	**FH (n = 13)**	**C (n = 28)**	**B3 (n = 47)**
Relative distance (m·min^{-1})	55.0 ± 7.58 ^{g}	59.4 ± 5.55	56.3 ± 8.63 ^{g}	61.3 ± 11.9	64.5 ± 7.31	63.5 ± 4.52	64.4 ± 7.76 ^{a,c}
Peak velocity achieved (m·s^{-1})	6.14 ± 0.77 ^{f,g}	6.32 ± 0.54 ^{g}	6.51 ± 0.96 ^{g}	6.56 ± 0.71 ^{g}	6.95 ± 0.68	7.27 ± 0.81 ^{a}	7.92 ± 0.56 ^{a,b,c,d}
Percentage of maximum velocity achieved (%)	82.6 ± 8.18 ^{f,g}	83.9 ± 6.60 ^{g}	82.9 ± 11.4 ^{g}	84.8 ± 9.22	86.8 ± 7.97	90.2 ± 7.10 ^{a}	91.4 ± 5.77 ^{a,b,c}
Relative distance < 1 m·s^{-1} (m·min^{-1})	9.47 ± 1.21 ^{f,g}	9.85 ± 0.80	11.4 ± 1.94	10.2 ± 1.45	11.6 ± 1.19	11.6 ± 1.38 ^{a}	11.5 ± 1.67 ^{a}
Relative distance at 1.01–3.00 m·s^{-1} (m·min^{-1})	29.6 ± 4.63	29.0 ± 3.58	27.7 ± 5.18	29.0 ± 5.12	31.1 ± 3.88	31.4 ± 3.23	30.2 ± 4.21
Relative distance at 3.01–5.00 m·s^{-1} (m·min^{-1})	14.6 ± 5.39	18.7 ± 3.65	15.6 ± 7.92	18.9 ± 7.46	17.7 ± 5.38	16.9 ± 2.69	16.9 ± 4.48
Relative distance at 5.01–5.50 m·s^{-1} (m·min^{-1})	0.85 ± 0.81 ^{d,e,f,g}	1.14 ± 0.92 ^{e,g}	1.05 ± 0.52 ^{f,g}	1.65 ± 0.95 ^{a}	2.07 ± 0.62 ^{a,b}	1.74 ± 0.63 ^{a,c}	2.09 ± 0.73 ^{a,b,c}
Relative distance at > 5.50 m·s^{-1} (m·min^{-1})	0.55 ± 0.76 ^{e,f,g}	0.79 ± 0.89 ^{g}	0.66 ± 0.62 ^{g}	1.60 ± 1.67	2.01 ± 1.24 ^{a}	1.92 ± 1.12 ^{a}	3.73 ± 2.10 ^{a,b,c}

FR = front row, 2R = second row, BR = back row, SH = scrum half, FH = fly half, C = center, B3 = back three. $^{a, b, c, d, e, f, g}$ significantly different from FR, 2R, BR, SH, FH, C, and B3, respectively.

Discussion

This study provides valuable descriptive data regarding the physical match demands of international women's rugby union while also investigating the influence of playing position on relative demands of match play. Similar to previous studies (Sheppy *et al.*, 2020; Callanan, Rankin and Fitzpatrick, 2021; Woodhouse *et al.*, 2021a), playing position had a significant effect on physical match demands in the present study, with the exception of relative distances at velocities of 1.01–3.00 and 3.01–5.00 $m \cdot s^{-1}$. Total distance separated by position in the present study was 3232–5173 m, which is similar to previously reported top-ranked international female rugby union players (3240–5283 m) (Woodhouse *et al.*, 2021a), but lower than the 5784 and 5820 m reported in other international cohorts (Suarez-Arrones *et al.*, 2014; Sheppy *et al.*, 2020). This distance is also lower than the 4982 m reported for English premiership players (Bradley *et al.*, 2020). The higher absolute values reported for other international cohorts were likely due to the decision to only include match files from players who took part in ≥60 min of match play (Bradley *et al.*, 2020; Sheppy *et al.*, 2020) or complete match files (Suarez-Arrones *et al.*, 2014) compared to the present study, which included all match files regardless of playing time. Relative distance for the present cohort (59.6 $m \cdot min^{-1}$) was lower than that previously reported in international and club-level female rugby (65.9–68.3 $m \cdot min^{-1}$) (Suarez-Arrones *et al.*, 2014; Callanan, Rankin and Fitzpatrick, 2021; Woodhouse *et al.*, 2021a). Given that peak velocity achieved in the present study (6.8 $m \cdot min^{-1}$) was higher than that previously reported (6.1 $m \cdot min^{-1}$) (Suarez-Arrones *et al.*, 2014), and collision frequency (0.46 collisions per min) was also higher than that previously reported (Woodhouse *et al.*, 2021a), the lower relative distance in the present study may have been due to contextual match constraints, i.e., technical and tactical factors.

Total distance covered at > 5.5 $m \cdot s^{-1}$ accounted for ~2.5% of the total distance, which was higher than the ~1.2% previously reported in a similarly ranked cohort (Suarez-Arrones *et al.*, 2014), but similar to the ~2.7% reported for a top-ranked team (Woodhouse *et al.*, 2021a). Distance covered at high velocities, rather than the absolute distance covered during match play was posited as a differentiating factor between top- and lower-ranked teams (Whitehead *et al.*, 2021). This has not yet been found in female rugby union and may warrant further investigation. Due to the similarities observed in the physical match demands of the current cohort to those of a top-ranked professional team, it may be that factors other than physical match demands are the key differentiating factors between top- and lower-ranked teams, i.e., technical and tactical ability.

Akin to previous reports (Sheppy *et al.*, 2020; Woodhouse *et al.*, 2021a), FR and SH covered the least total distances, but similar to these studies, this observation can be attributed to substitution strategy, with FR and SH playing fewer minutes than those in other positions. FR displayed lower relative distances and peak velocities than those of backs (C and B3), which is consistent with that previously reported in international cohorts (Woodhouse *et al.*, 2021a). Relative running demands are similar between the back positional groups, with no differences found apart from SH displaying lower peak velocity achieved in match play than that in B3. Similarly, no differences were found between the different forward positions (FR, 2R, and BR) for relative demands. The current cohort displayed a higher homogeneity of relative demands across positional groups (forwards and backs) than that previously reported (Sheppy *et al.*, 2020; Woodhouse *et al.*, 2021a), but this may be attributable to the larger number of match files used in those studies.

Collision frequency by position (ranging from 0.23 to 0.89 collisions per min) in the present study was higher than that previously reported in women's international rugby union (0.17 to 0.33 collisions per min) (Woodhouse *et al.*, 2021a) and in male rugby union (0.18 to 0.44 collisions per min) (MacLeod *et al.*, 2018). These differences may have been the result of specific tactical approaches adopted by teams during these specific matches. Women's rugby union has adopted more possession-driven attacking tactics compared to increased kicking frequency in the male game (Hughes *et al.*, 2017). This open and continuous style of play in the female game may explain the increased collision frequency. There is also a large difference in sample size and number of matches captured in the present study compared to previous analysis of women's international rugby union (n = 260, 12 matches vs. n = 967, 53 matches) (Woodhouse *et al.*, 2021a). This likely resulted in the latter cohort being exposed to a wider range of teams of varying tactical strategy and technical ability, which may explain the differences in collision frequency reported.

An important consideration is that all data presented in the present study were collected across the 2020, 2021, and 2022 championships, which coincided with the COVID-19 global pandemic. The pandemic caused a significant disruption to the normal functioning of the Women's Six Nations Championship including delays, the rescheduling of matches, the cancellation of matches, and the restriction of spectator attendance. COVID-19 restrictions and public health policies may have also impacted training scheduling and player availability.

There are several limitations to this study; however, they are not unique to this investigation, but rather characteristic of this research area. The present study utilized data from only one team, which may have limited its application to other elite teams given the complex and contextual nature of match demands (Dalton-Barron *et al.*, 2020). Inconsistency in methodological approaches across studies specifically regarding inclusion/exclusion criteria and application of velocity thresholds hinders direct comparison. Classification issues due to a lack of consensus regarding velocity thresholds may be compounded further in female team sports due to limited research (Sweeting *et al.*, 2017). The reported data describe the physical match demands, but do not account for the influence of differing tactical strategies adopted by the team and/or their opposition; thus, these data should be interpreted with an appreciation of relevant contextual factors, e.g., weather conditions, the level of opposition, playing style, and match significance. Ball-in-play data were not collected in the present study, which could significantly influence the relative intensity and collision frequency (Pollard *et al.*, 2018). Practitioners should, therefore, be cognizant of potential contextual factors when interpreting the data provided in this study.

Since the completion of this investigation, it has been announced that the international team, which is the focus of the present study, intend to offer a number of professional contracts to players, effectively transitioning into a semiprofessional environment ('Irish Rugby | McDarby Appointed Head Of Women's Performance & Pathways', no date). All other amateur teams competing in the Women's Six Nations Championship have recently announced similar intentions (*Contracts for 30 Scotland Women rugby players and two new semi-pro teams as part of four-year plan to grow the game*, 2022; *Italy reward 25 players with central contracts*, 2022; *Wales Women award 17 further contracts as Cunningham extends stay*, 2022); thus, the 2023 Women's Six Nations Championship, for the first time, will consist of only professional and semiprofessional teams rather than also including amateur teams. Future research should investigate factors other than physical match demands that differentiate high- and lower-ranked teams.

Conclusions

The present study provided descriptive data of the physical demands of match play from an elite, amateur, women's international rugby union team competing in the Women's Six Nations Championship across a three-year period. Total running demands were similar to those previously reported in other international cohorts employing similar methodology, but the number of collisions per minute was higher than that previously reported in similar cohorts. Differences in the physical demands were found between positions, and practitioners should be aware of the broad demands of match play and position-specific differences when designing training programs. Training methodologies for elite-level female rugby union players should consider the unique demands across positional groups with specific consideration of high-velocity running and collision frequency.

Previous chapters have shown that coaches perceive distinct differences between males and females in terms of baseline physical and performance characteristics. It has been argued that a myriad of factors, ranging from innate physiological differences to inequalities in support structures, contribute to the observed differences in the physical performance characteristics of male and female athletes. The previous chapters have also highlighted that differences in response to resistance exercise training are perceived by some coaches and that female-specific issues relating to menstruation may negatively impact physical performance and training ability/adherence.

The following chapter reports the findings of a systematic review and meta-analysis which explored sex differences in baseline differences and resistance exercise training-induced hypertrophy, power, and strength outcomes. This chapter quantifies the mean difference between untrained males and females in lean body mass and muscular strength and also examines the differences in effects between males and females for hypertrophy and strength outcomes following matched resistance exercise training interventions.

The chapter begins with a brief discussion of some key relevant literature related to sexual dimorphisms, specifically in the musculoskeletal system. I argue that previous meta-analyses in this area have some fatal methodological flaws which limit interpretation and that no previous studies have examined muscular power-related outcomes. The chapter then explains the methodology used by employing a multivariate maximum likelihood random-effects model. The results show that significant baseline differences in anthropometric and muscular strength measures exist between untrained males and females and will provide pragmatic quantitative measures of these differences. The results also showed that males and females responded in a similar way to matched resistance training for hypertrophy and lower body strength outcomes, with females displaying a superior effect on upper body strength. I will then explore the underlying mechanism which explains the significant sexual dimorphism observed in the untrained baseline differences. I will also critically discuss potential explanations and propose a hypothesis for the superior effect observed in females on upper body strength. The chapter will then highlight that further research related to power outcomes needs to be conducted, before highlighting some of the limitations of this study.

Chapter 6 – Study 5

Sex Differences in Baseline Differences and Resistance Exercise Training Induced Hypertrophy, Power, and Strength: A Systematic Review with Meta-Analysis

Presented in manuscript format.

Nolan D., Darragh I., Germaine M., Lynch A., Manninen M., Egan B. Sex Differences in Baseline Differences and Resistance Exercise Training Induced Hypertrophy, Power, and Strength: A Systematic Review with Meta-Analysis

Abstract

Resistance exercise training is commonly used by athletic populations as part of a comprehensive athletic development training program, eliciting morphological and neurological adaptations which contribute to changes in muscle hypertrophy, power and strength. Between-sex differences are evident in many systems of the human body. These between-sex differences are particularly evident in the musculoskeletal system, specifically regarding body composition, muscle structure, and absolute muscular strength. This systematic review with meta-analysis aimed to; i) quantify the mean absolute and standardised between-group differences in untrained males and females at baseline for fat-free mass, upper body strength, lower body strength, and lower body power; and ii) examine between-group differences comparing males and females regarding hypertrophy, upper body strength, lower body strength, and lower body power in adaptations to resistance exercise training. A systematic review with meta-analysis was conducted on experimental studies conducted before June 2022. The search using the online databases PUBMED, SPORTDiscus, Web of Science, Embase, and other supplementary search strategies yielded 4,468 articles, with 29 articles meeting the inclusion criteria. The articles were analysed using a meta-analytic multilevel maximum likelihood estimator model. The results indicate there are significant differences at baseline between untrained males and females for absolute fat-free mass (RMD = 19.35, CI 95% [17.41, 21.29], $z = 19.53$, $p = <0.001$), upper body strength (*SMD* = 2.88, CI 95% [2.67, 3.10], z = 23.47, $p < 0.001$) and lower body strength (*SMD* = 2.14, CI 95% [1.84, 2.44], z = 16.21, $p < 0.001$). In response to resistance exercise training, no significant differences were found for either hypertrophy ($g = 0.26$, CI 95% [-1.00, 1.51], $z = 0.40$, $p = 0.68$), or lower body strength ($g = 0.10$, CI 95% [-0.06, 0.25], t = 1.38, $p = 0.19$). A significant effect in favour of females was observed for upper body strength outcomes ($g = -0.39$, CI 95% [-0.53, -0.26], t = -6.35, $p = <0.001$). These

analyses would suggest that there are significant differences in anthropometric and physical performance characteristics between untrained males and females; however, males and females respond in a similar manner to resistance exercise training for hypertrophy and lower body strength, with females displaying an advantage for relative upper body strength.

Introduction

Resistance exercise training is commonly used by athletic populations as part of a comprehensive athletic development training program (Schoenfeld *et al.*, 2021). Resistance exercise training elicits morphological (i.e., increased muscle fiber/whole muscle cross-sectional area, change in muscle fiber pennation angle, and increases in the proportion of non-contractile tissues) and neurological (i.e., increased motor unit activation, firing frequency, and synchrony of high threshold unit) adaptations which contribute to changes in muscle hypertrophy, power and strength (Egan and Sharples, 2023).

Between-sex differences (often referred to as sexual dimorphisms) are evident in many systems of the human body, that is, there are mean systematic differences in function and structure between biological males and females. These mean differences are evident in pre-natal development, during childhood, and widen throughout puberty, resulting in differences between males and females in factors such as anthropometric profiles, muscle strength and force-time characteristics, which can influence exercise performance and adaptations (Hilton and Lundberg, 2021). These between-sex differences which influence exercise performance capacity are largely driven by differences in gonadal hormone concentrations i.e., testosterone, oestrogen, and progesterone (McCarthy, Nugent and Lenz, 2017).

These between-sex differences are particularly evident in the musculoskeletal system, specifically regarding body composition i.e., the quantity and ratios and both fat-free mass and fat mass (males displaying on average 45% higher lean body mass and 30% less fat mass (Janssen *et al.*, 2000)), muscle structure (males displaying higher ratios of type II to type I fibres (Haizlip, Harrison and Leinwand, 2015)), absolute muscular strength (males displaying 57% greater grip strength and 54% greater leg strength (Neder *et al.*, 1999; Bohannon *et al.*, 2019)), and connective tissue properties (males displaying 83% higher tendon force capabilities and 41% higher tendon stiffness (Lepley *et al.*, 2018)). These mean differences result in what has been coined the "male advantage" in sports; that is, on average, males display superior performance outputs across the majority of sports (Hilton and Lundberg, 2021).

It has been argued that females are largely underrepresented in the exercise science literature (Costello, Bieuzen and Bleakley, 2014; Cowley *et al.*, 2021), and thus, may require different approaches to resistance exercise training rather than simply prescribing methodologies developed from an androcentric-focused paradigm (Santos, Turner and Bycura, 2022). Despite this, a previous meta-analysis (including studies published prior to 1st January, 2018) showed that males and females have a similar relative adaptive response to resistance exercise training for hypertrophy and lower body strength, with females displaying higher relative effects for upper body strength (Roberts, Nuckols and Krieger, 2020). However, the previous meta-analysis included studies employing a concurrent training intervention (i.e. a combination of resistance exercise training and cardiovascular endurance exercise training) and, in one instance, anabolic steroid users in their analysis.

An updated meta-analysis examining studies using only resistance exercise training interventions and examining other physical qualities related to sports performance (i.e. power) is warranted. Therefore, this systematic review with meta-analysis aimed to; i) quantify the mean absolute and standardised between-group differences in untrained males and females at baseline for fat-free mass, upper body strength, lower body strength, and lower body power; and ii) examine between-group differences comparing males and females regarding hypertrophy, upper body strength, lower body strength, and lower body power in adaptations to resistance exercise training.

Methods

Literature Search and Management

All items in this protocol correspond with the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols Statement (PRISMA-P; (Page *et al.*, 2021)) The literature used in this meta-analysis was obtained before June 1st, 2022, from the following databases; PUBMED, SPORTDiscus, Web of Science, and Embase. The first author (DN) gathered the literature from the databases using the following search string for all databases: (gender OR sex OR "sex differences" OR "gender differences") AND (“exercise training” OR "resistance training" OR "strength training" OR "power training" OR “plyometric training” OR “jump training”) AND (strength OR hypertrophy OR power OR sprint OR mobility OR "rate of force development" OR rfd OR speed OR jump OR stiffness OR flexibility OR rsi OR dsi OR "reactive strength index" OR "dynamic strength index" OR eur OR "eccentric utilisation ratio" OR "eccentric utilization ratio" OR ligament OR “ligament properties” OR tendon OR "tendon properties")

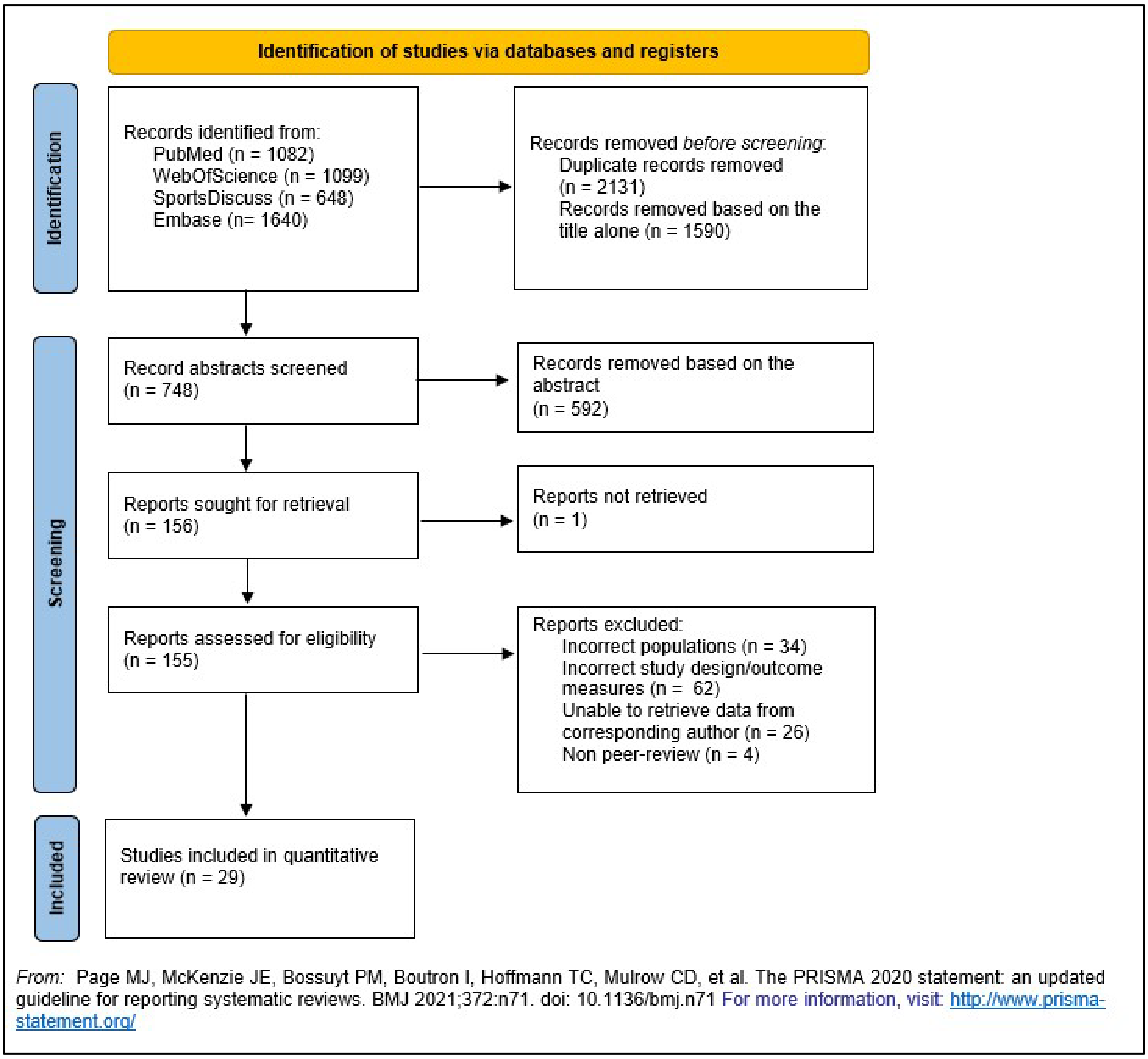

Figure 5. PRISMA flow diagram. Detailed flow of studies examined from the initial search to the final inclusion.

In addition to the database search, the reference lists of all the included studies and relevant review studies found in the search were assessed. Moreover, a backward search using Google Scholar was conducted for all included studies. Duplicate articles were excluded from the analyses. Two pairs of authors (MG/DN & ID/AL) independently scanned each article identified from the searches by applying the exclusion and inclusion criteria to the titles and abstracts. Each study carried forward from this stage was fully read and reviewed independently by the same authors, aiming to determine the studies to be meta-analysed. Conflicting opinions were resolved via discourse between the authors, with the last author (BE) acting as mediator if necessary. Reasons for exclusion of studies were recorded and are displayed in figure 5.

Study Selection

Research publications were considered eligible if the following inclusion criteria were met: 1) all research made available prior to January 12th, 2023; 2) were in English language and peer-reviewed; 3) were experimental in design; 4) used a resistance exercise training intervention (resistance exercise training was defined as interventions in which the muscles contract against an external resistance with the intent of inducing adaptations resulting in increases in hypertrophy, power, or strength); 5) measured upper body muscular strength *(assessed by either bench press or chest press one-repetition maximum)*, lower body muscular strength *(as assessed by either back squat or leg press one-repetition maximum),* lower body power *(assessed by counter movement jump),* or hypertrophy *(assessed as whole body fat-free mass by DXA)* outcomes; 6) at least two data points (pre- and post-measures); 7) included healthy biological female and male participants with a mean age of ≥18 and ≤ 40 years; 8) used training interventions ≥ 4 weeks in length; 8) males and female followed matched resistance exercise training protocols. The exclusion criteria were as follows:1) age <18 or > 40 years; 2) concurrent training interventions; and 3) use of training interventions ≤ 4 weeks in length.

Data Extraction, Moderators, and Study Quality

The two pairs of authors independently extracted the sample sizes, means, and standard deviations (SD)/standard errors (SE) of the outcome measures from each study. Where data were not reported, allowing for appropriate extraction, requests for data were made by contacting the corresponding author. The authors were contacted a maximum of three times with a one-week time interval between contact efforts. If the email address of the author was not working or was not publicly available, the private message function of the ResearchGate website was used as the method of contact. All the described techniques were applied when we did not receive missing information from the study authors, as suggested by the Cochrane Handbook (*Cochrane Handbook for Systematic Reviews of Interventions*, no date). Any dissimilarities in the extracted data were resolved before the final calculations were completed.

In addition to quantitative information, *a priori* moderators were extracted, including characteristics of the experimental interventions (length of intervention, supervision status, mode of resistance training, number of exercises, training frequency, number of sets, intensity, and rep ranges used), participant characteristics (mean age, height, body mass, and training status), and features of the paper (country, publication year, and lab group). Any dissimilarities were resolved before the final calculations were completed.

The methodological quality of the included studies was assessed using the "Tool for the assessment of study quality and reporting in exercise" (TESTEX) (Smart *et al.*, 2015). TESTEX is a 12-item scale divided into two sections: study quality (items 1-5) and study reporting (items 6-12), and represents a modified version of the PEDro scale (Maher *et al.*, 2003). Each question is answered with "yes" if the criteria are satisfied or with a "no" if the criteria are not satisfied; only the answer "yes" corresponds to one point. In item 8, there are three questions, each of which can be scored with a point equating to a maximum of three points. Similarly, for Item 10, the maximum number of points was two. The maximum number of points that can be scored on the checklist is 15.

Calculation of Effect Sizes

All outcomes were analysed as either raw mean differences or differences between mean change differences (Hedge's *g*) between the female and male conditions in R (version 4.0.5; R Core Team, 2022) using the escalc function in the metafor package (Viechtbaur, 2010). Standardised mean change for the female and male conditions were computed using the pre-test standard deviations and a bias correction factor (Berkey *et al.*, 1998). As the pre–post-test correlations were not available in the studies, an estimate correlation of 0.7 was used to compute the standardised mean changes, while also testing alternative correlations of 0.5 and 0.9. The difference in the standardised mean changes was then computed by subtracting the standardised mean change of the female condition from that of the male condition (Morris, 2008). The corresponding sampling variances were computed by summing the sampling variances for the two conditions.

Statistical Analysis

A multivariate maximum likelihood random effects model (Berkey *et al.*, 1998) was fitted to the data using R (version 4.0.5; R Core Team, 2018) and the Metafor package (Viechtbauer, 2010). The adopted meta-analytic multivariate approach handles the non-independence of the effect sizes by including a variance-covariance matrix in the model (Berkey *et al.*, 1998). As the exact magnitude of dependence of the effects was unknown, robust variance estimator from the clubSandwich package was used to improve the accuracy of the estimates (Pustejovsky and Tipton, 2022).

In the multivariate model, random effects were added for each effect size within each study allowing the effect sizes to correlate and have different variances. Parameters of *tau2* and *I2* were used to examine the between-study heterogeneity of the effects (Higgins *et al.*, 2003). Further, as the *Q* statistic for heterogeneity cannot be applied to multivariate models, a likelihood ratio test examining the effect of *tau2* on all the outcomes was used as an indicator of significant between study heterogeneity. The between study heterogeneity of the effect sizes was indicated if likelihood ratio test

($\chi 2$) reached a significance level of $p < .05$, and the sampling error contributed to the observed variance less than 75% (Hedges and Olkin, 2014).

Interactions of the moderators were not tested because of low between-study heterogeneity and inadequate numbers of effects for each outcome (*Analysing Data and Undertaking Meta-Analyses - Cochrane Handbook for Systematic Reviews of Interventions - Wiley Online Library*, no date). A modified version of the Egger's test (Egger *et al.*, 1997) using the standard error of the observed outcomes as a predictor in a multivariate model and a visual examination of the contour enhanced funnel plots were used to detect publication bias. The presence of outlier and influential studies and effects were analysed using Cook's distances and the distribution of studentized residuals (Viechtbauer and Cheung, no date).

The sensitivity analyses were computed at several levels. First, alternative pre-post correlations in computing the effect sizes, as well as different autocorrelations in computing the variance-covariance matrix, were examined. Second, the impact of excluding outlier and influential studies and effects were analysed. Third, different combinations of the two sensitivity analysis protocols were examined.

Results

A total of 102 effects (k) from 29 studies for untrained fat-free mass raw differences (k = 8), untrained upper body strength differences (k = 13), untrained lower body strength differences (k = 14), hypertrophy training response (k = 9), upper body strength training response (k = 26), and lower body strength training response (k = 32) were included. Lower body power was not meta-analysed because of an inadequate number of outcomes (k = 3). The study selection process from the initial search to final inclusion is shown in Figure 5. The total number of participants was 1288 (48.3% female). The mean age of the participants was 23.78 ±2.27 years. The exercise intervention lasted between 6 and 24 weeks, with a mean duration of 13.37 ±5.97 weeks, with a mean number of 2.93 ±0.42 sessions per week. The complete descriptive information of the included studies is presented in Table 8.

Table 8. Descriptive Information on Studies Meeting Inclusion Criteria

Study	***n***	**Frequency**	**Training Status**	**Study Duration (wks)**	**Relevant Outcomes**
Almstedt et al., 2011 (Almstedt *et al.*, 2011)	Male: 10 Female: 10 Control: Male: 4 Female: 5	3 $d.wk^{-1}$	Recreationally Active	24	**Strength** 1RM: • Back Squat • Bench Press
Bell et al., 1997 (Bell *et al.*, 1997)	Male: 6 Female: 8	3 $d.wk^{-1}$	Recreationally Active	16	**Strength** 1RM: • Leg Press • Bench Press
Bell et al., 2000 (Bell *et al.*, 2000)	Male: 7 Female: 4 Control: Male: 5 Female: 5	3 $d.wk^{-1}$	Recreationally Active	12	**Strength** 1RM: • Leg Press
Buford et al., 2007 (BUFORD *et al.*, 2007)	Male: 20 Female: 10	3 $d.wk^{-1}$	Trained	9	**Strength** 1RM: • Bench Press • Leg Press
Colliander & Tesch, 1991 (Colliander and Tesch, 1991)	Male: 11 Female: 11	3 $d.wk^{-1}$	Untrained	12	**Power** Jump Height: • Counter Movement Jump
Cyrino et al., 2019 (Cyrino *et al.*, 2019)	Male: 28 Female: 31	3 $d.wk^{-1}$	Untrained	16	**Strength** 1RM: • Bench-Press • Back Squat

Fernandez-Gonzalo et al., 2014 (Fernandez-Gonzalo *et al.*, 2014)	Male: 24 Female: 16	2-3 d.wk^{-1}	Recreationally Active	6	**Power** Jump Height: • Counter Movement Jump **Strength** 1RM: • Leg Press
Guadalupe-Grau et al., 2009 (Guadalupe-Grau *et al.*, 2009)	Male: 20 Female: 8 Control: Male: 23 Female: 15	3 d.wk^{-1}	Recreationally Active	9	**Hypertrophy** DXA: • Whole Body Fat-Free Mass **Strength** 1RM: • Leg Press
Hurlbut et al., 2002 (Hurlbut *et al.*, 2002)	Male: 25 Female: 26	3 d.wk^{-1}	Untrained	24	**Hypertrophy** DXA: • Whole Body Fat-Free Mass **Strength** 1RM: • Chest Press • Leg Press
Ivey et al., 2000a (Ivey, Roth, *et al.*, 2000)	Male: 11 Female: 11	3 d.wk^{-1}	Untrained	9	**Hypertrophy** DXA: • Whole Body Fat-Free Mass
Ivey et al., 2000b (Ivey, Tracy, *et al.*, 2000)	Male: 11 Female: 9	3 d.wk^{-1}	Untrained	9	**Hypertrophy** DXA: • Whole Body Fat-Free Mass

Jozsi et al., 1999 (Jozsi *et al.*, 1999)	Male: 6 Female: 9	2 d.wk^{-1}	Untrained	12	**Strength** 1RM: • Chest Press • Leg Press
Kittilsen et al., 2021 (Kittilsen *et al.*, 2021)	Male: 11 Female: 11	3 d.wk^{-1}	Untrained	8	**Strength** 1RM: • Leg Press
Kojic et al., 2021 (Kojic, Mandic and Ilic, 2021)	Male: 12 Female: 12	2 d.wk^{-1}	Untrained	7	**Strength** 1RM: • Back Squat
Kosek et al., 2006 (Kosek *et al.*, 2006)	Male: 13 Female: 11	3 d.wk^{-1}	Untrained	16	**Hypertrophy** DXA: • Whole Body Fat-Free Mass **Strength** 1RM: • Back Squat • Leg Press
Lemmer et al., 2000 (Lemmer *et al.*, 2000)	Male: 10 Female: 8	3 d.wk^{-1}	Untrained	9	N/A
Lemmer et al., 2001 (Lemmer *et al.*, 2001)	Male: 10 Female: 9	3 d.wk^{-1}	Untrained	24	**Hypertrophy** DXA: • Whole Body Fat-Free Mass **Strength** 1RM: • Chest Press • Leg Press
Lemmer et al., 2007 (Lemmer *et al.*, 2007)	Male: 10 Female: 8	3 d.wk^{-1}	Untrained	24	**Hypertrophy** DXA: • Whole Body Fat-Free Mass

Marsh et al., 2020 (Marsh *et al.*, 2020)	Male: 22/23 Female: 41/42	3 $d.wk^{-1}$	Untrained	12	**Strength** 1RM: • Leg Press (n=41/23) • Bench Press (n=42/22)
Mayhew et al., 2011 (Mayhew *et al.*, 2011)	Male: 85 Female: 61	3 $d.wk^{-1}$	Untrained	12	**Strength** 1RM: • Bench Press
Ribeiro et al., 2014a (A.S. Ribeiro *et al.*, 2014)	Male: 30 Female: 34	3 $d.wk^{-1}$	Untrained	16	**Strength** 1RM: • Bench Press
Ribeiro et al., 2014b (Alex S. Ribeiro *et al.*, 2014)	Male: 58 Female: 65	3 $d.wk^{-1}$	Untrained	16	**Strength** 1RM: • Bench Press
Ribeiro et al., 2017 (Ribeiro *et al.*, 2017)	Male: 28 Female: 30	3 $d.wk^{-1}$	Untrained	16	**Strength** 1RM: • Back Squat • Bench Press
Rissanen et al., 2022 (Rissanen *et al.*, 2022)	Intervention Group 1: Male: 12 Female: 11 Intervention Group 2: Male: 11 Female: 11	2 $d.wk^{-1}$	Trained	8	**Power** Jump Height: Counter-Movement Jump **Strength** 1RM: • Back Squat • Bench Press
Ritti-Dias et al., 2005 (Dias *et al.*, 2005)	Male: 23 Female: 15	3 $d.wk^{-1}$	Untrained	8	**Strength** 1RM: • Bench Press • Back Squat
Roth et al., 2001 (Roth *et al.*, 2001)	Male: 8 Female: 6	3 $d.wk^{-1}$	Untrained	24	**Hypertrophy** DXA:

					• Whole Body Fat-Free Mass **Strength** 1RM: • Leg Press • Chest Press
Salvador et al., 2009 (Salvador *et al.*, 2009)	Male: 33 Female: 23	3 d.wk^{-1}	Untrained	8	**Strength** 1RM: • Bench Press • Back Squat
Sawan et al., 2021 (Abou Sawan *et al.*, 2021)	Male: 10 Female: 10	3 d.wk^{-1}	Untrained	8	**Strength** 1RM: • Bench Press • Leg Press
Schwanbeck et al., 2020 (Schwanbeck *et al.*, 2020)	Intervention Group 1: Male: 7 Female: 11 Intervention Group 2: Male: 8 Female: 10	4 d.wk^{-1}	Trained	8	**Strength** 1RM: • Bench Press • Back Squat

Differences in Untrained Participants Prior to Engaging in Resistance Exercise Training

Fat Free Mass – Raw Mean Difference

For fat-free mass measured by DXA, 8 effects from 8 studies were analysed. The two-level random effects model indicated a significant raw mean difference favouring males of 19.35 kg (CI 95% [17.41, 21.29], $z = 19.53$, p = <0.001). Heterogeneity was low (I^2 = 0.00%). The two-level random effects modelling also estimated a mean quantity of fat-free mass of 61.48 kg (CI 95% [59.77, 63.18], z = 70.62, p <0.001) in males and 42.14kg (CI 95% [40.84, 43.44], z = 63.54, p <0.001) in females. Heterogeneity was low in both of these models (males; $I^2 = 15.29\%$, females; $I^2 = 11.24\%$).

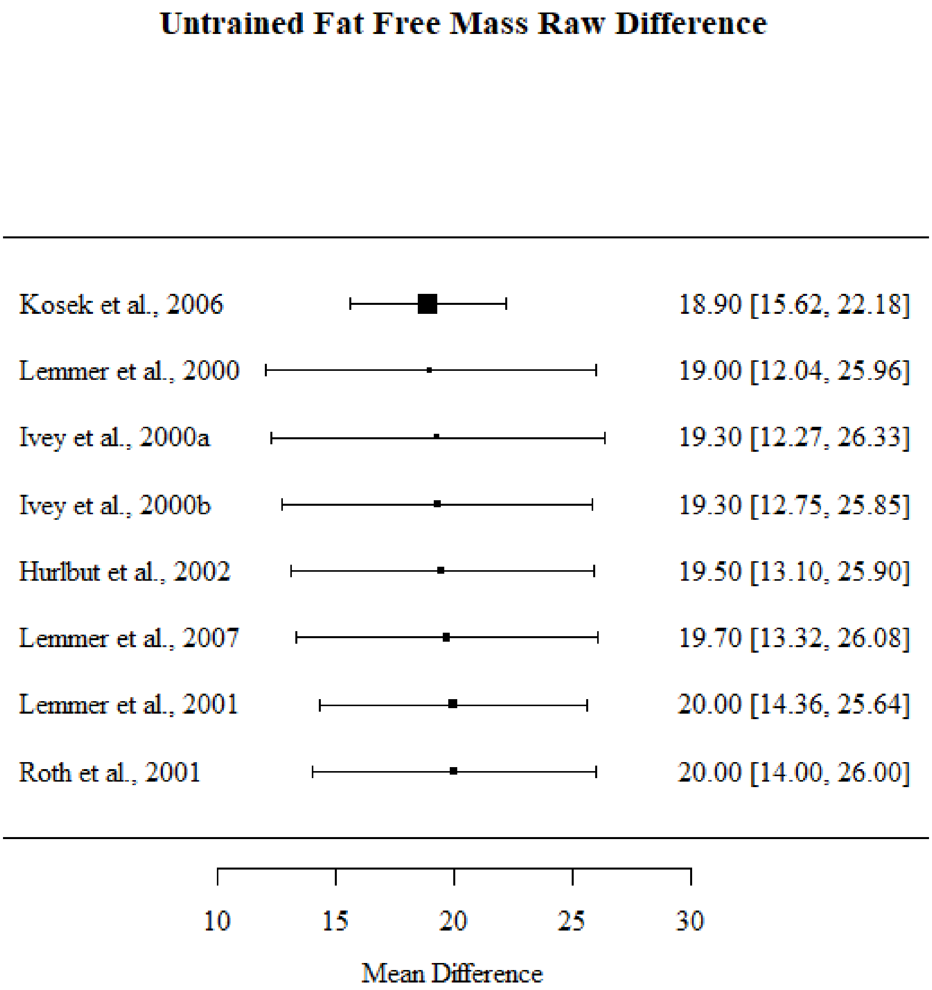

Figure 6. Forest plot of fat-free mass raw differences in untrained participants.

Upper Body Strength – Bench and Chest Press Model

For upper body strength, including measures of bench press and chest press, 13 effects from 13 studies were analysed. The multivariate random effects model indicated a standardised mean difference of 2.88 (CI 95% [2.67, 3.10], z = 23.47, p < 0.001). ($tau^2_{between\text{-}studies}$ = 0.00, $tau^2_{within\text{-}studies} = 0.00$, $I^2 = 0.00\%$). Multivariate modelling using maximum likelihood estimator indicated the raw mean difference (favoring males) was 32.30 kg (CI 95% [27.51, 37.10], t = 14.53, p < 0.001) for the bench press and 29.38 kg (CI 95% [24.70, 34.05], t = 17.19, p < 0.001) for the chest press.

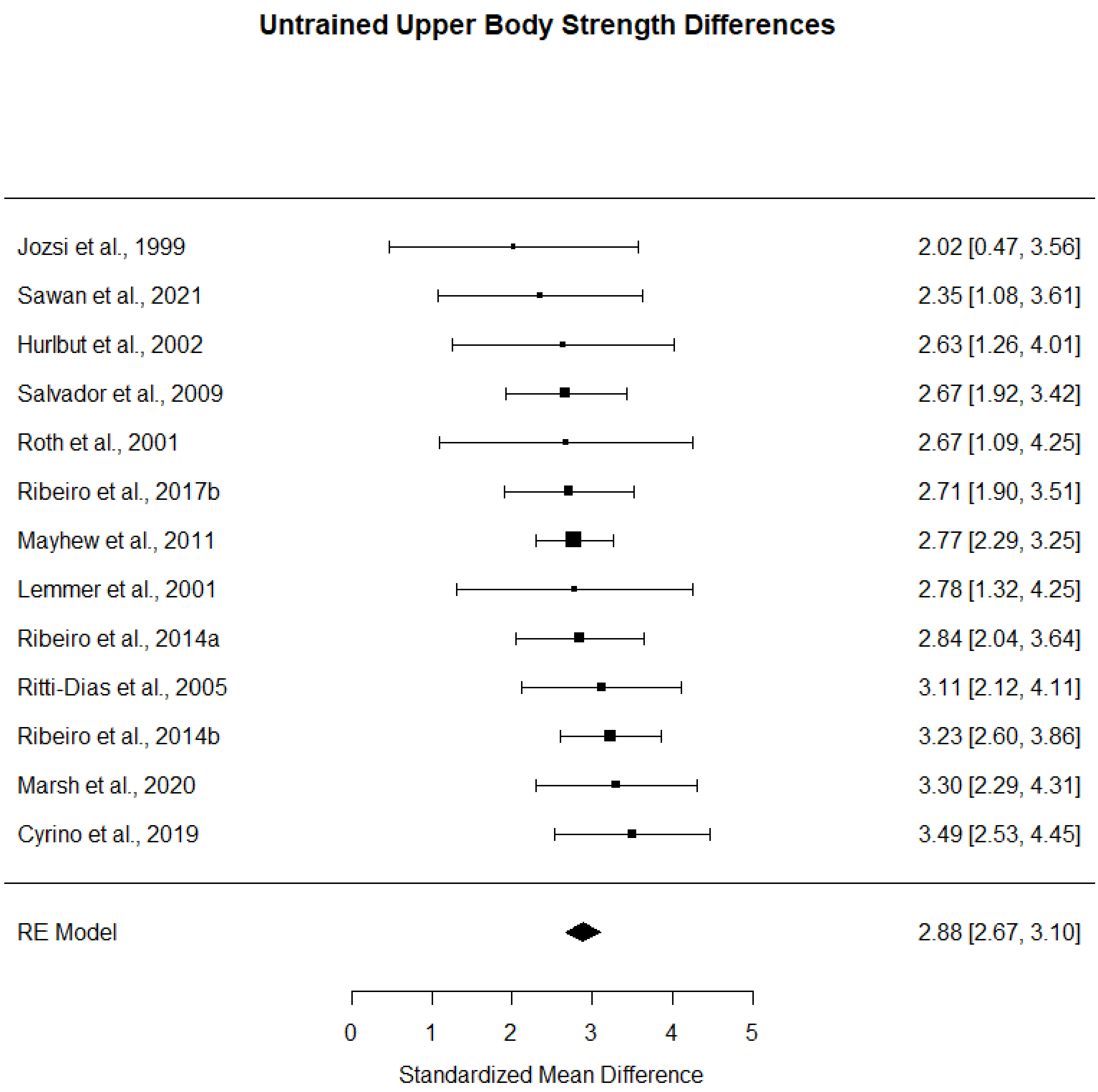

Figure 7. Forest plot of standardised mean differences in upper body strength of untrained participants.

Lower Body Strength – Squat and Leg Press Model

For lower body strength, including measures of squat and leg press, 14 effects from 13 studies were analysed. The multivariate random effects model indicated a standardised mean difference of 2.14 (CI 95% [1.84, 2.44], z = 16.21, p < 0.001). Heterogeneity was low ($tau^2_{between\text{-}studies}$ = 0.00, $tau^2_{within\text{-}studies}$ = 0.02, I^2 = 6.78%). Multivariate modelling using maximum likelihood estimator indicated the raw mean difference (favoring males) was 44.42 kg (CI 95% [39.00, 49.84], t = 19.53, p < 0.001) for the back squat and 143 kg (CI 95% [78.13, 208.39], t = 4.90, p < 0.001) for the leg press.

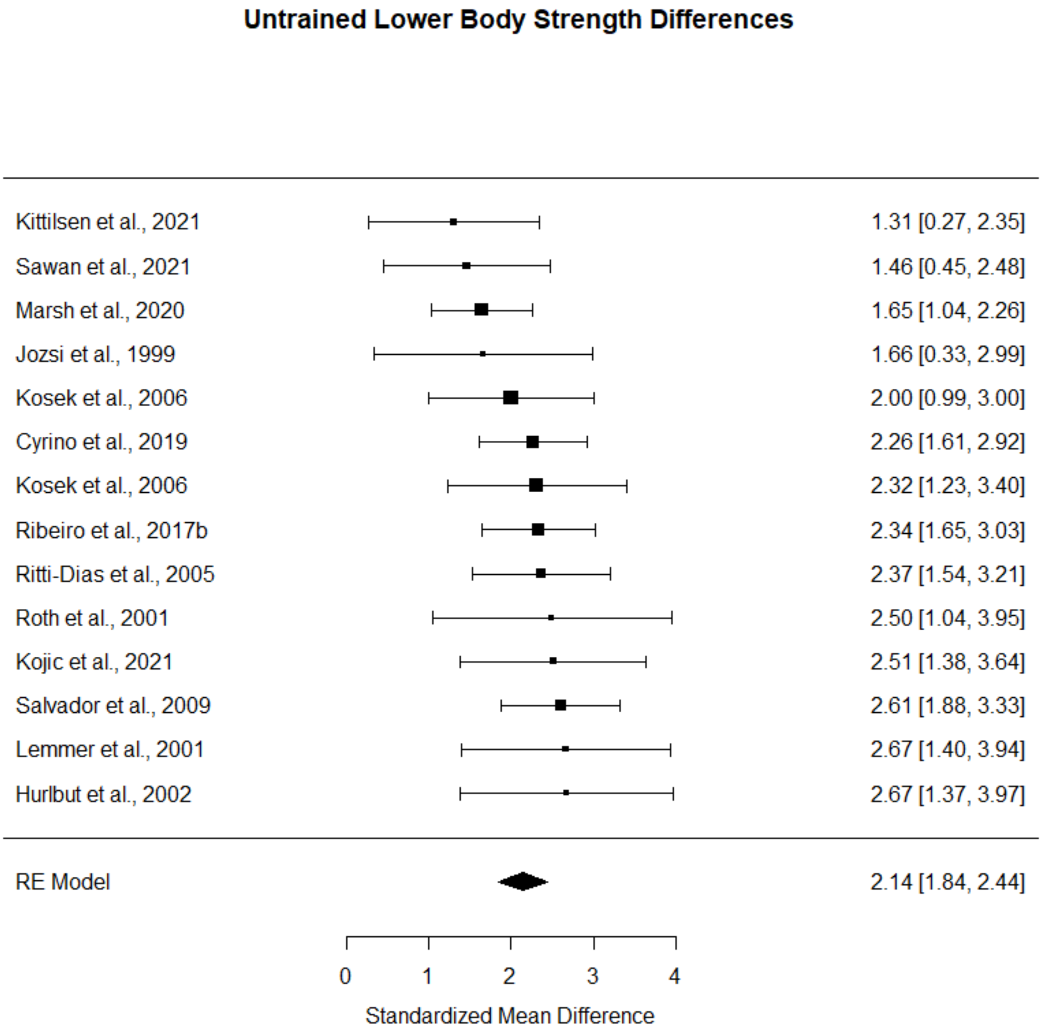

Figure 8. Forest plot of standardised mean differences in lower body strength of untrained participants.

Differences in Response to Resistance Exercise Training

Fat-Free Mass

For changes in fat-free mass measured by DEXA, 9 effects, from 9 studies were analysed, with 89% of the outcome estimates being positive (favouring males), ranging from 0.00 to 0.33. There was no significant effect between the conditions, with two-level random effects model indicating that the mean change difference was 0.26 (CI 95% [-1.00, 1.51], z = *0.40, p* = 0.68). Heterogeneity was low (tau^2 = 0.00, I^2 = 0.00%).

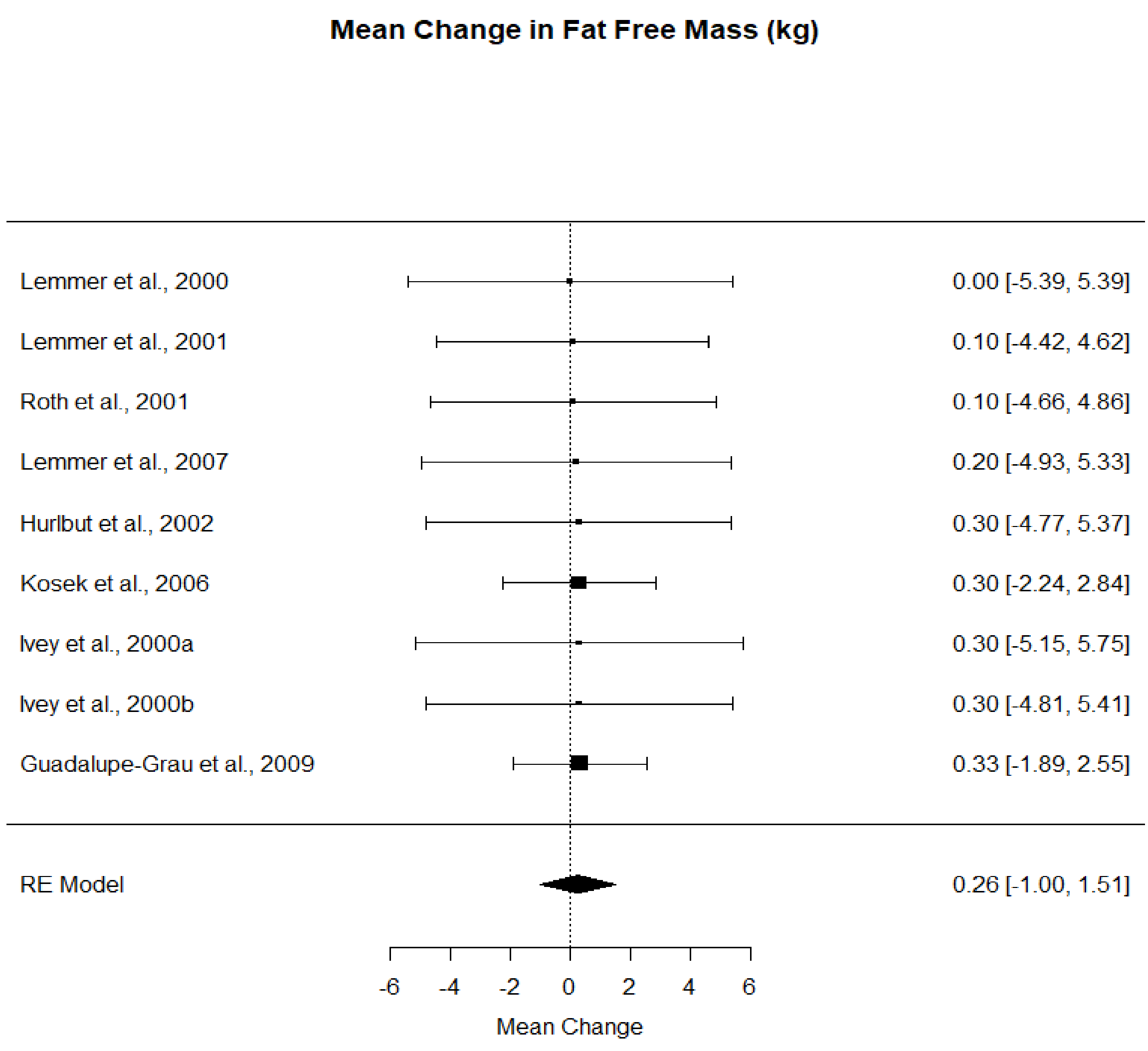

Figure 9. Forest plot of between-group differences in hypertrophy outcomes for males and females in response to resistance exercise training. Effects >0 indicate a larger magnitude of effect for males.

Upper Body Strength – Bench Press and Chest Press Model

For upper body strength outcomes, 26 effects from 18 studies were analysed, with 88% of the outcome estimates being negative (favouring females), ranging from −1.57 to 0.14. There was a significant effect between conditions with the multivariate model indicating that the standardised mean change difference was -0.39 (CI 95% [-0.53, -0.26], t = -6.35, *p* = <0.001). Heterogeneity was low ($tau^2_{between\text{-}studies}$ = 0.00, $tau^2_{within\text{-}studies}$ = 0.01, I^2 = 4.47%).

The effect sizes aggregated at the study level (one effect per study displayed per outcome) and their CIs as well as the standardised mean change difference according to a meta-analytic multivariate model and a two-level random effects models are displayed in Figure 11.

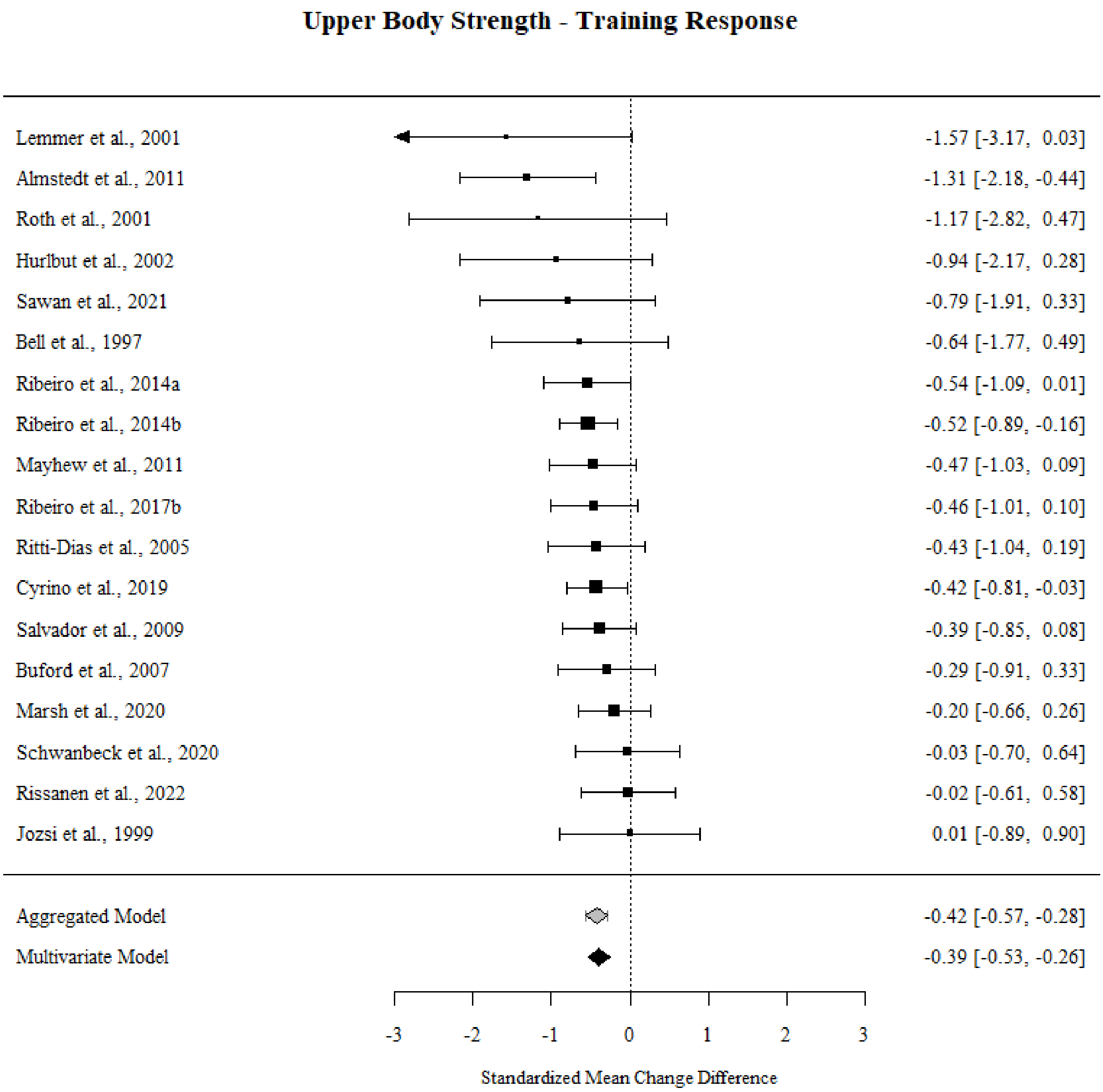

Figure 10. Forest plot of between-group differences in upper body strength outcomes for males and females in response to resistance exercise training. Effects >0 indicate a larger magnitude of effect size for males.

Lower Body Strength – Back Squat and Leg Press Model

For lower body strength outcomes, 32 effects from 21 studies were analysed, with 53% of the outcome estimates being positive (favouring males), ranging from −2.29 to 3.49. There was no significant effect between conditions with the multivariate model indicating that the standardised mean change difference was 0.10 (CI 95% [-0.06, 0.25], t = 1.38, p = 0.19). Heterogeneity was low ($tau^2_{between\text{-}studies}$ = 0.00, $tau^2_{within\text{-}studies}$ = 0.04, I^2 = 17.97%)

The effect sizes aggregated at the study level (one effect per study displayed per outcome) and their CIs as well as the standardised mean change difference according to a meta-analytic multivariate model and a two-level random effects models are displayed in Figure 12.

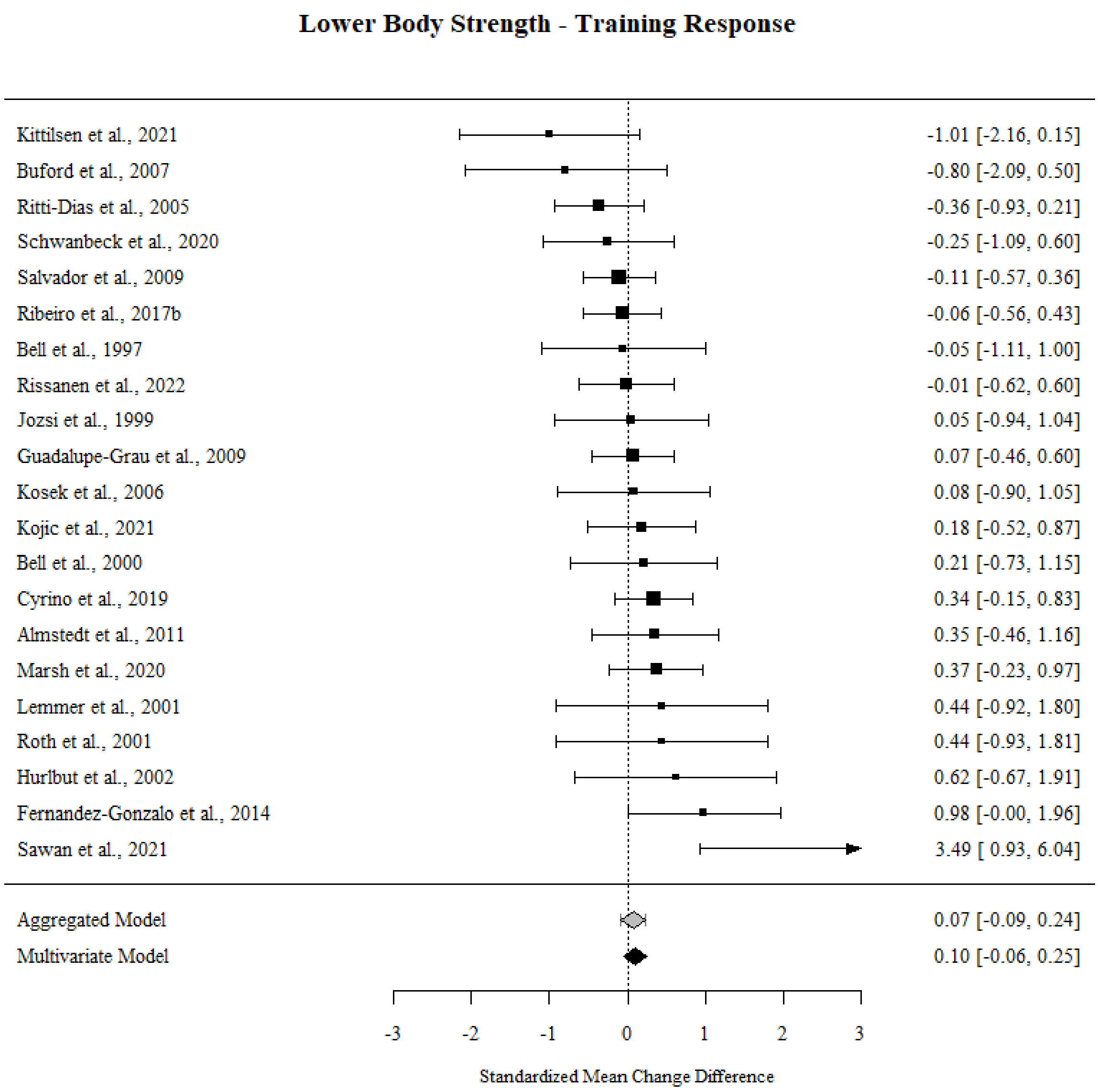

Figure 11. Forest plot of between-group differences in lower body strength outcomes for males and females in response to resistance exercise training. Effects >0 indicate a larger magnitude of effect size for males.

Sensitivity, Publication Bias and Moderator Analysis

The sensitivity analysis did not result in any significant changes in any of the models. Moderator analysis was deemed unnecessary because of low between-study heterogeneity. Publication bias (i.e., publication of studies with results of certain type and direction) was examined by visual examination of normal and contour-enhanced funnel plots using a modified Egger's test (Egger *et al.*, 1997). For the funnel plots, an aggregated effect from each study was plotted so that only one effect size per study per outcome is displayed. There was no evidence of publication bias for any outcomes.

Discussion

This meta-analysis had two primary aims. First, to quantify the mean baseline differences between untrained males and females in measures relating to lean body mass, muscular strength, and muscular power. Second, to examine differences between males and females for hypertrophy, strength and power outcomes in response to matched resistance exercise training. Baseline mean differences between males and females were reported for lean body mass, upper body strength, and lower body strength. In response to resistance exercise training, similar effect sizes were observed between males and females for hypertrophy and lower body strength outcomes, with a greater magnitude of effect for females reported for upper body strength. Differences in muscular power were not examined because of an insufficient number of effects. These analyses would suggest that there are differences in anthropometric and physical performance characteristics between untrained males and females; however, males and females respond in a similar manner to resistance exercise training for hypertrophy and lower body strength, with females displaying a larger effect for relative upper body strength. Further investigations on muscular power outcomes are warranted.

Although there are well-established between-sex differences in musculoskeletal functional and structural characteristics (Hilton and Lundberg, 2021), this meta-analysis synthesised and quantified these differences, and to our knowledge is the first to do so. Untrained males were shown to have significantly higher lean body mass than females, displaying a mean difference of 19.35kg *(CI 95%*

[17.41, 21.29], z = 19.53, p = <0.001). Untrained males were also shown to be significantly stronger than females for both upper body *(SMD = 2.88, CI 95% [2.67, 3.10], z = 23.47, p < 0.001)* and lower body *(SMD = 2.14, CI 95% [1.84, 2.44], z = 16.21, p < 0.001)* strength outcomes. Simply put, the analysis showed that the average untrained male can bench press ~32 kg and back squat ~45 kg more than the average untrained female.

Clear physiological mechanisms exist to explain these significant baseline differences between the sexes and are evident throughout the life course. In the neonatal and early life (first 3-6 months) periods, humans experience a “minipuberty”, that is, activation of the hypothalamic-pituitary-gonadal axis (Lanciotti *et al.*, 2018), resulting in high gonadotropin and sex steroid levels. This “minipuberty” results in higher growth velocity in the first six months of life for males, conveying an “imprinting effect” on BMI and bodyweight (Becker and Hesse, 2020). Additionally, more than 3000 genes are differentially expressed in male and female skeletal muscle, which may influence their composition and structure (Haizlip, Harrison and Leinwand, 2015); for example, females display a higher proportion of type I fibres in certain muscles (e.g. vastus lateralis and biceps brachii) (Roberts *et al.*, 2018). While between-sex differences related to athletic performance have been argued by some to be inconsequential prior to puberty (Tønnessen *et al.*, 2015), these phenotypical sex differences in skeletal muscle may explain the “male advantage” observed in children aged 6 (broad jump 9.7% further), and 9 years (broad jump 9.5% further, completed 33% more push-ups in 30s, and displayed 13.8% higher grip strength), respectively (Catley and Tomkinson, 2013; Tambalis *et al.*, 2016). During puberty, the development of secondary sexual characteristics is driven by a myriad of factors which result in chronically increased endogenous circulating levels of gonadal hormones (i.e., testosterone, oestrogen, and progesterone). During puberty, males display circulating testosterone levels at least 15-times that of females, inducing changes in muscle mass, muscle strength and anthropometric variables (Handelsman, Hirschberg and Bermon, 2018), further widening the structural and functional sex-differences in the musculoskeletal system. These phenotypic differences largely explain the significant differences in fat-free mass and absolute muscular strength observed between males and female in the current analyses.

Despite these significant differences between males and females in baselines levels of fat-free mass, similar increases in hypertrophy were observed in response to resistance exercise training for males and females (MD = 0.26, CI 95% [-1.00, 1.51], z = *0.40*, p = 0.68). These findings are broadly in agreement with those of Roberts et al. (Roberts, Nuckols and Krieger, 2020). While the baseline sex differences in fat-free mass discussed above are driven primarily by the androgenising effects of increased circulating testosterone levels in males experienced during puberty, the role of testosterone (and other circulating anabolic hormones) in modulating the adaptive response to resistance exercise training remains unclear (Egan and Sharples, 2023), with systemic hormone concentrations not being associated with resistance exercise training-induced hypertrophy in males (Morton *et al.*, 2016, 2018). Similarly, there is no strong evidence to suggest that fluctuating concentrations of primary female sex hormones (i.e. oestrogen and progesterone) observed in healthy, naturally menstruating females influence strength or hypertrophy adaptations to resistance exercise training (Colenso-Semple *et al.*, 2023). Our analysis suggests that the markedly different hormonal milieus displayed in young, healthy males and females does not result in differing relative effects on skeletal muscle hypertrophy in response to resistance exercise training. While absolute differences in skeletal muscle size, fibre type composition, and strength exist between males and females, contractile properties at the single fibre level are similar between the sexes (Trappe *et al.*, 2003), which may also partly explain the similar hypertrophy effects observed in this analysis. I would contend that it is logical to infer that similar single fibre contractile properties between the sexes may suggest that the physiological and molecular response to the stimulus of resistance exercise training is similar. In fact, no sex-differences are apparent in post resistance exercise training myofibrillar protein synthesis (West *et al.*, 2012), mixed muscle protein fractional synthetic rate, or mTOR signalling response (Dreyer *et al.*, 2010).

Resistance exercise training-induced increases in muscular strength is the product of a series of neuromuscular adaptations, with initial, rapid improvements in strength resultant primarily due to neurological changes (i.e., improved motor unit activation, firing frequency, and synchrony of high threshold motor units), with subsequent increases predominantly a result of muscular changes (increased muscle fiber cross-sectional area, change in muscle fiber angle of pennation, and increased proportion of non-contractile tissue) (Egan and Sharples, 2023) . Lower body strength increases were similar between the sexes (SMD = 0.10, CI 95% [-0.06, 0.25], t = 1.38, *p* = 0.19), with a significant effect, in favour of females, found for upper body strength (SMD = -0.39 CI 95% [-0.53, -0.26], t = -6.35, *p* <0.001). Again these findings are similar to those of Roberts et al. (Roberts, Nuckols and Krieger, 2020). There may be some neuromuscular differences between the sexes, which may explain the superior effect of upper-body strength in females. Between-sex difference appears to exist in acute fatigability during high-intensity performance bouts which could be argued to influence performance during matched resistance exercise training interventions; however, this has largely been observed in isometric-based tasks rather than isotonic contractions (Hunter, 2016). Additionally, while this difference is observed in acute fatigue during isometric contractions, the same divergence is not observed in recoverability of neuromuscular function following dynamic and eccentric focused resistance exercise training sessions (Lee *et al.*, 2017; Marshall *et al.*, 2020; Morawetz *et al.*, 2020). The majority of included studies involved either untrained or recreationally active participants with a mean intervention length of ~13 weeks; therefore, a significant proportion of the observed strength increases likely resulted from neurological adaptations. I would contend that social differences in play (McCarthy, Nugent and Lenz, 2017), coupled with attitudes and practices towards sport and physical activity (Guthold *et al.*, 2018) result in the average untrained female likely displaying lower levels of relative fitness compared to untrained males, particularly in gross upper body movements (i.e., pushing and pulling). Additionally, the majority of studies (~76%) were conducted in the United States of America, where resistance exercise training is a routine component of many male physical education programs (Kern, Bellar and Wilson, 2023; Kern *et al.*, 2023). Therefore, although the male participants may have self-reported as untrained, they may have had more familiarity with the resistance exercise training movements used in the interventions, specifically the bench press. Arguably, the favourable effect of upper-body strength adaptations observed in females may be a result of beginning the intervention in a "more untrained" state than their male counterparts, with males exhausting the rapid improvements due to neurological changes at an earlier point in the intervention, i.e., a ceiling effect. Few studies have examined the time course of neuromuscular adaptations to resistance exercise training in detail (Brown *et al.*, 2017), with even fewer including female participants to facilitate the evaluation of potential sex differences. Abe et al. (Abe *et al.*, 2000) compared the time course of strength and muscle thickness changes in males (n = 17) and females (n = 20) following 12-weeks of matched resistance training exercise. While the authors concluded that the time-course and relative increases in strength and muscle thickness were similar for both men and women, it was reported that a statistically significant increase for chest press occurred by week 4 in the female group but did not occur until week 6 in males. To my knowledge, no studies have provided a detailed analysis of sex differences in the time course of neuromuscular adaptations to resistance exercise training and further research may be warranted. While differences in baseline fitness and subsequent time course of adaptation provide a plausible theoretical basis to explain the results observed in the present thesis and that of Roberts et al. (Roberts, Nuckols and Krieger, 2020), studies with larger sample sizes, increased testing frequency and sensitivity, and longer intervention lengths are required to empirically investigate this potential mechanism.

The magnitude of response to resistance exercise training varies extensively between individuals for both hypertrophy (-11 – 30%) and strength (-8 – 60%) outcomes (Ahtiainen *et al.*, 2016). This heterogeneity further increases the difficulty of detecting both within- and between-group differences, particularly when sensitive measures are required to detect small magnitudes of changes, such as during the early phases of a resistance exercise training intervention. This high level of variability is also important to acknowledge in the context of meta-analyses, and while the current findings align with a previous meta-analysis in a similar cohort (Roberts, Nuckols and Krieger, 2020), a meta-analysis in older adults showed no differences between males and females for upper-body strength outcomes in response to resistance exercise training; however, older females gained significantly more relative lower body strength than males (Jones *et al.*, 2021). Overall, I concede that there are relatively few neuromuscular differences between the sexes that may explain the differences observed in upper body strength but acknowledge that this may be a result of non-homogeneity of training status between the groups, or the result of the chosen statistical approach rather than a physiological phenomenon.

Despite standardised effects on hypertrophy and lower body strength, and females displaying a favourable effect on relative upper body strength, the pragmatic interpretation of this must be clearly understood. For all outcomes, males had significantly greater outcomes in absolute terms. Simply put, when simply measuring the amount of muscle gained or the load increased in the one-repetition maximum tests, males increased to a greater magnitude than females. Practitioners should not interpret the lack of differences in standardised mean effects as synonymous with no practically measurable differences whatsoever.

Power outcomes were not assessed in many studies, despite it being argued as one of the most important determinants of athletic performance (Cronin and Sleivert, 2005). Future studies should consider adding these outcomes to their testing protocols, even if the training intervention is not specifically designed to improve power production, as interventions that increase maximal strength also lead to meaningful improvements in power-related outcomes (e.g. counter-movement jump), particularly in untrained cohorts (Suchomel, Nimphius and Stone, 2016; Comfort *et al.*, 2018). These power-related measures could be easily and inexpensively incorporated into a testing protocol and could contribute valuable data to this understudied performance characteristic. Future research should also be cognisant of providing detailed reporting of the methodology employed, particularly relating to the specific details of the resistance training exercise intervention (i.e. exercises used, number of reps/set prescribed and achieved, intensity used, rest periods, frequency, supervision status, etc.). Improved reporting would allow for increased accuracy in the comparison and exploration of the moderating factors. Additionally, a large number of studies which satisfied the inclusion criteria reported only group means and did not provide sex-level comparisons in their data. Despite persistent efforts to obtain raw data from the corresponding authors, sex-level data were not obtained in several studies which satisfied the inclusion criteria. Authors should consider fully reporting their data and providing full datasets, including participant-level data, in publicly available repositories where possible, which may make the process of meta-analysis more statistically robust and efficient (Hansford *et al.*, 2022). There are also limitations to this study which should be acknowledged. Firstly, the majority of participants were untrained, limiting extrapolations for athletic or highly trained populations. The included studies did not provide details regarding the occupation or habitual physical activity levels of the participants which could potentially confound their results. The strength models only included specific compound exercises. The inclusion of studies with single-joint outcome measures (e.g., elbow-flexion, or knee-extension) may facilitate larger number of effects and increased complexity in the models, potentially yielding differing results.

Conclusion:

This systematic review with meta-analysis conducted a between-group comparison of young males and females to quantify baseline differences in hypertrophy, power and strength in untrained individuals and examine differences in response to matched resistance exercise training for hypertrophy, power and strength outcomes. These analyses would suggest that there are significant differences in anthropometric and physical performance characteristics between untrained males and females; however, males and females respond in a similar manner to resistance exercise training for hypertrophy and lower body strength, with females displaying an advantage for relative upper body strength. Further investigations on muscular power outcomes are warranted.

Previous chapters have shown that coaches have failed to account for the potential impact of HC use on acute performance and chronic adaptations to resistance exercise training, with some coaches describing it as a "blind spot". Previous chapters have also shown that approximately half of female rugby players use HCs, with a high proportion reporting HC related perceived side-effects. Given the high prevalence of use, perceived side-effects and lack of specific knowledge from coaches, research investigating the potential influence of HC use on adaptations to resistance exercise training.

The following chapter reports the findings of a systematic review and multilevel meta-analysis which explored the effect of HC use on skeletal muscle hypertrophy, power, and strength adaptations in response to resistance exercise training.

The chapter begins with a brief discussion of some key relevant literature related to HC use and its potential impact on acute performance and skeletal muscle adaptations in response to resistance exercise training. I highlight that this research question has now yet been explored throughout systematic review and meta-analytical synthesis. The chapter then explains the methodology used by employing a multilevel multivariate maximum likelihood random-effects model. The results show that only the effect of OCP use skeletal muscle adaptation to resistance exercise training has been examined in the literature to date. The results show that OCP use does not positively or negatively influence hypertrophy, power, or strength adaptations in females partaking in resistance exercise training.

I will critically discuss potential explanations for these findings and the potential mechanisms by which oestrogen and progesterone may influence skeletal muscle adaptations in response to resistance exercise training. The chapter will then highlight that further research related to power outcomes needs to be conducted, before highlighting some of the limitations of this study.

Chapter 7 – Study 6

The effect of hormonal contraceptive use on skeletal muscle hypertrophy, power, and strength adaptations to resistance exercise training: a systematic review and multilevel meta-analysis.

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Abstract

Resistance exercise training is widely used by general and athletic populations to increase skeletal muscle hypertrophy, power, and strength. Endogenous sex hormones influence various bodily functions, including possibly exercise performance, and may influence adaptive changes in response to exercise training. Hormonal contraceptive (HC) use modulates the profile of endogenous sex hormones, and therefore, there is increasing interest in the impact, if any, of HC use on adaptive responses to resistance exercise training. This study aimed to provide a quantitative synthesis of the effect of HC use on skeletal muscle hypertrophy, power, and strength adaptations in response to resistance exercise training. A systematic review with meta-analysis was conducted on experimental studies conducted before January 2023. The search using the online databases PUBMED, SPORTDiscus, Web of Science, Embase, and other supplementary search strategies yielded 4,567 articles, with eight articles (54 effects and 325 participants) meeting the inclusion criteria. All included studies investigated the influence of oral contraceptive pills (OCP), with no study including participants using other forms of HC. The articles were analysed using a meta-analytic multilevel maximum likelihood estimator model. The results indicate that OCP use does not have a significant effect on hypertrophy (g = 0.00, CI 95% [-0.12, 0.13], t = *0.08,* p = 0.94), power (g = -0.04, CI 95% [-0.93, 0.84], t =*-0.29,* p = 0.80), or strength (g = 0.10, CI 95% [-0.08, 0.28], t =*1.48,* p = 0.20). Based on the current analysis, there is no evidence-based rationale to advocate for or against the use of OCPs in females partaking in resistance exercise training to increase hypertrophy, power, and/or strength. Rather, an individualised approach considering

an individual's response to OCPs, their reasons for use, and menstrual cycle history may be more appropriate.

Keywords

female; lean body mass; oestrogen; oral contraceptive pill; progestin;

Key points

- When comparing OCP users to non-users, OCP use has no significant effect on skeletal muscle hypertrophy, power, or strength adaptations in response to resistance exercise training.
- Based on the current analysis, there is no evidence-based rationale to advocate for or against the use of OCPs in females partaking in resistance exercise training to increase hypertrophy, power, and/or strength.
- To date, studies investigating the influence of HCs on adaptations to resistance exercise training have exclusively investigated OCPs, and future research should also examine the potential influence of different HC types.

Introduction

Resistance exercise training is strongly encouraged for the general population because of its myriad of associated health benefits (Sawan *et al.*, 2023) and is widely used by athletic populations as part of a comprehensive athletic development training program (Schoenfeld *et al.*, 2021). Resistance exercise training elicits morphological (i.e., increased muscle fibre/whole muscle cross-sectional area, change in muscle fibre pennation angle, and increases in the proportion of non-contractile tissues) and neurological (i.e., increased motor unit activation, firing frequency, and synchrony of high threshold unit) adaptations which contribute to changes in skeletal muscle hypertrophy, power and strength (Egan and Sharples, 2023). Higher levels of muscle strength are associated with superior force-time characteristics (e.g., rate of force development and increased external mechanical power), general sport-related skill performance (e.g., jumping, sprinting, and change of direction), and a decreased risk of injury (Suchomel, Nimphius and Stone, 2016).

Hormonal contraceptives (HCs), which involve the administration of exogenous hormones that affect endocrine regulation of the female reproductive system (De Leo *et al.*, 2016; Elliott-Sale and Hicks, 2018), are used by a sizeable proportion of individuals in both general (~28–43%) (Cea-Soriano *et al.*, 2014; Nations, 2019) and athletic (~40–51%) (Torstveit and Sundgot-Borgen, 2005; Martin *et al.*, 2018a; Nolan, Elliott-Sale and Egan, 2023) populations. HCs are classified according to the hormones employed; combined HCs have both oestrogenic and progestin components, whereas other HCs have a progestin-only component. HCs are also administered using various delivery methods, with the oral contraceptive pill (OCP) being the most commonly used form (Nations, 2019; Elliott-Sale *et al.*, 2020). Combined OCPs reduce endogenous concentrations of 17 beta oestradiol and progesterone (compared to the mid-luteal phase of the menstrual cycle), acting via negative feedback on the gonadotrophic hormones, chronically downregulating the hypothalamic-pituitary-ovarian axis (Elliott-Sale *et al.*, 2020). Dependent on if, and how, the dosages of exogenous hormones vary across the OCP cycle, the combined OCPs can be monophasic (i.e., consistent dosage), biphasic (i.e., two levels of dosage), or triphasic (i.e., three levels of dosage), and are also are classified by “generation”, categorised by the form of progestin used (Shahnazi *et al.*, 2014).

Endogenous sex hormones influence various bodily functions and may also influence exercise performance (McNulty *et al.*, 2020). HC use has equivocal effects on acute measures of athletic performance (Elliott-Sale *et al.*, 2020), yet the majority of literature to date is of low quality, with small sample sizes, lack of standardisation, and inadequate familiarisation, among the important issues that limit interpretation. Relatedly, the impact of HC use on adaptive responses to resistance exercise training has been the subject of increasing interest, with positive (molecular markers) (M. Oxfeldt *et al.*, 2020), negative (hypertrophy, strength, inflammation) (Ruzić, Matković and Leko, 2003a; Ihalainen, Hackney and Taipale, 2019; Riechman and Lee, 2022), and neutral (hypertrophy, strength, power) (Nichols *et al.*, 2008; Wikström-Frisén, Boraxbekk and Henriksson-Larsén, 2017a; Dalgaard *et al.*, 2019; Romance *et al.*, 2019; Myllyaho *et al.*, 2021; Dalgaard *et al.*, 2022; Sung *et al.*, 2022a) outcomes being observed in HC users compared to non-users. Lack of consistent findings on the influence of exogenous hormones on resistance exercise training adaptations contributes to confusion in females and those that work with them, when trying to make an informed decision on whether or not hormonal contraception is likely to impact athletic performance and/or training adaptations. Given the mixed findings to date, and absence of evidence-based recommendations exist for sportswomen and practitioners who work with them, this review aimed to investigate the influence of HCs on skeletal muscle hypertrophy, power, and strength adaptations in response to resistance exercise training.

Methods

Literature Search and Management

All items in this protocol correspond with the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols Statement (PRISMA-P; (Page *et al.*, 2021); See Electronic Supplementary Material) The review protocol was registered on PROSPERO (ID number and hyperlink: CRD42022365677) on December 3rd, 2022. The literature used in this meta-analysis was obtained before January 12th, 2023, from the following databases; PUBMED, SPORTDiscus, Web of Science, and Embase. The first author (DN) gathered the literature from the databases using the following search string for all databases: *("contraceptive" OR "contraceptives" OR "hormonal" OR "birth control")AND ("exercise" OR "resistance training" OR "resistance exercise training" OR "hypertrophy training" OR "weightlifting" OR "bodybuilding" OR "athletic training" OR "strength training" OR "power training" OR "plyometric training" OR "jump training" OR "physical training") AND ("strength" OR "hypertrophy" OR "mobility" OR "power" OR "sprint" OR "rate of force development" OR "RFD" OR "speed" OR "jump" OR "stiffness" OR "reactive strength index" OR "dynamic strength index" OR "flexibility" OR "RSI" OR "DSI" OR "EUR" OR "eccentric utilisation ratio" OR "eccentric utilization ratio" OR "tendon" OR "ligament").*

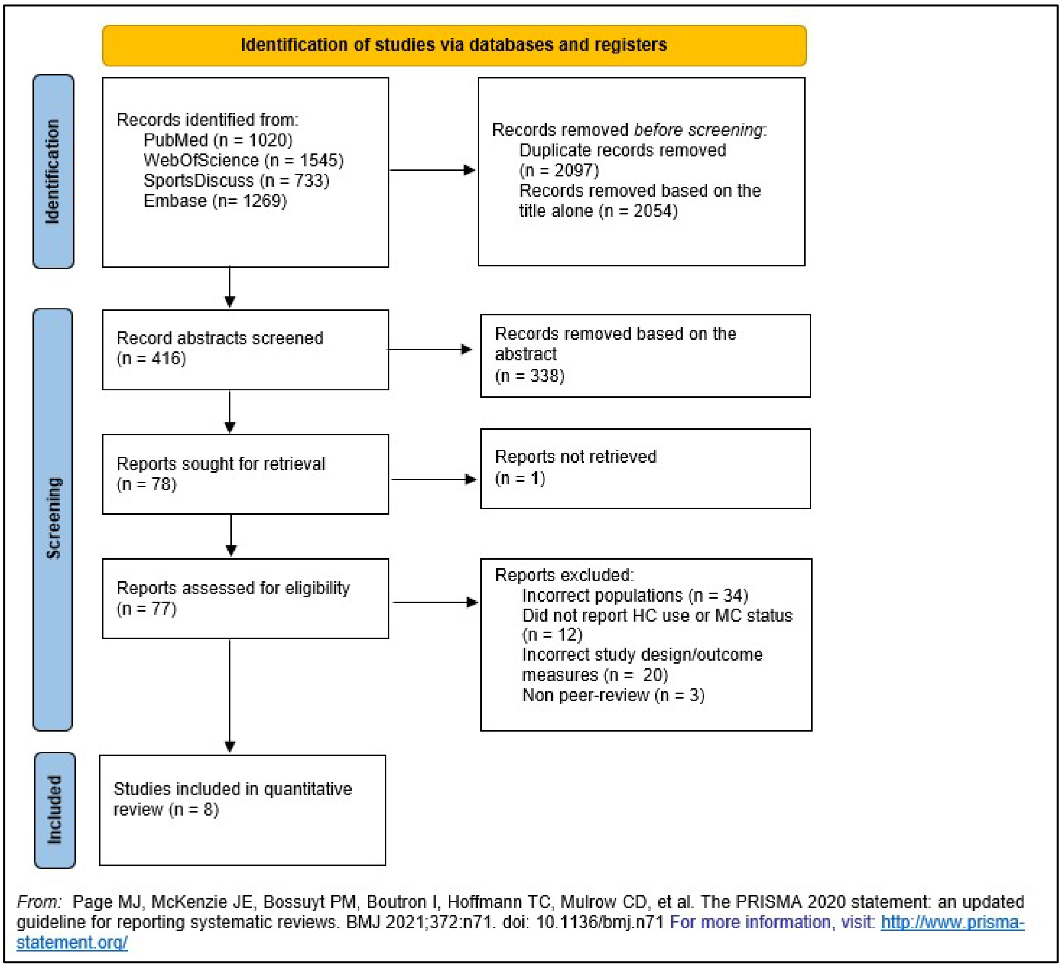

Figure 12. PRISMA flow diagram. Detailed flow of studies examined from the initial search to the final inclusion.

In addition to the database search, the reference lists of all the included studies and relevant review studies found in the search were assessed. Moreover, a backward search using Google Scholar was conducted for all included studies. All duplicate articles were removed. The first two authors (DN and KLN) independently assessed each article identified from the searches by applying the exclusion and inclusion criteria to the titles and abstracts. Each study carried forward from this stage was fully read and reviewed independently by these same authors, aiming to determine the studies to be included in the meta-analysis. Conflicting opinions were resolved via discourse between the first and second authors (DN and KLN), with the last authors (BE & MM) acting as mediators, if necessary. Reasons for exclusion of studies were recorded and are displayed in Figure 13.

Study Selection

Research publications were considered eligible if the following inclusion criteria were met: 1) all research made available prior to 12 January 2023; 2) were in English and peer-reviewed; 3) were experimental in design; 4) used a resistance exercise training intervention (resistance exercise training was defined as interventions in which the muscles contract against an external resistance with the intent of inducing adaptations resulting in increases in hypertrophy, power, or strength); 5) measured muscular hypertrophy, power, or strength outcomes; 6) at least two data points (pre- and post-measures); 7) included healthy biological female participants with a mean age of $\geq$18 and $\leq$ 40 years; 8) used training interventions $\geq$ 4 weeks in length; and 8) direct comparison of HC users and non-users. The exclusion criteria were as follows: 1) age <18 or > 40 years; 2) individuals with menstrual dysfunction or other comorbidities; 3) concurrent exercise training interventions; 4) used training interventions $\leq$ 4 weeks in length.

Data Extraction, Moderators, and Study Quality

The first two authors independently extracted sample sizes, means, and standard deviations (SD) or standard errors (SE) of the outcome measures from each study. Where data were not reported in sufficient detail, or did not allow for appropriate extraction, requests for data were made by contacting the corresponding author. The authors were contacted a maximum of three times with a one-week time interval between contact efforts. If the email address of the author was not working or was not publicly available, the private message function of the Research Gate website was used as the method of contact. In one study (Nichols *et al.*, 2008), statistical information was extracted from study figures using WebPlotDigitizer (Version 4.6, Pacifica, CA, USA). Two studies (M. Oxfeldt *et al.*, 2020; Dalgaard *et al.*, 2022) provided data from the same participants and intervention, as confirmed via direct communication with the corresponding author. Thus, the extracted data were considered to be from one study for the purpose of analysis. All described techniques were applied when we did not receive missing information from the study authors, as suggested by the Cochrane Handbook (*Cochrane Handbook for Systematic Reviews of Interventions*, no date). Inter-rater agreement for all extracted data used in the effect size calculation was assessed using an intraclass correlation coefficient (ICC) for continuous data. Any dissimilarities were located and resolved before the final calculations were completed.

In addition to quantitative information, *a priori* moderators were extracted, including characteristics of the experimental interventions (length of intervention, supervision status, mode of resistance training, number of exercises, training frequency, number of sets, intensity, and rep ranges used), participant characteristics (age, height, body mass, and training status), and features of the paper (country, publication year, and research group). Inter-rater agreement for all coded moderators was assessed as an unweighted Cohen's kappa. Dissimilarities, if any, were located and resolved before the final calculations were completed.

The methodological quality of the included studies was assessed using the "Tool for the assessment of study quality and reporting in exercise" (TESTEX) (Smart *et al.*, 2015). TESTEX is a 12-item scale divided into two sections: study quality (Items 1-5) and study reporting (Items 6-12), and represents a modified version of the PEDro scale (Maher *et al.*, 2003). The scale was modified for use in this review (see Appendix D). Items 2, 3, and 10, referring to randomisation of intervention groups, allocation concealment, and activity monitoring in control groups, respectively, were deemed irrelevant to the design of the studies in this current review and were removed. Two additional items (Items 2 and 10 in the modified version) were included: Q2. Were the participants confirmed to be habitual HC users or habitual non-users for at least 3 months prior to the study? Q10. Was the type of HC described to the level of detail required for categorisation or replication? Each question was awarded one point if the criteria were satisfied, with Items 5 and 7 containing three and two questions, respectively. The maximum number of points that could be scored on this modified 11-item checklist was 14.

Calculation of Effect Sizes

All the outcomes were analysed as in differences between mean change difference (Hedge's *g*) between the HC and non-HC conditions in R (version 4.0.5; R Core Team, 2022) using the escalc function in the metafor package (Viechtbaur, 2010). Standardised mean change for the HC and non-HC conditions were computed using the pre-test standard deviations and a bias correction factor (Berkey *et al.*, 1998). As the pre–post-test correlations were not available in the studies, an estimate correlation of 0.7 was used to compute the standardised mean changes, while also testing alternative correlations of 0.5 and 0.9. The difference in the standardised mean changes were then computed by subtracting the standardised mean change of the HC condition from the non-HC condition (Morris, 2008). The corresponding sampling variances were computed by summing the sampling variances of the two conditions.

Statistical Analysis

A multilevel maximum likelihood random effects model (Berkey *et al.*, 1998) was fitted to the data using R (version 4.0.5; R Core Team, 2022) and the Metafor package (Viechtbauer, 2010). The adopted meta-analytic approach utilised multilevel modelling to account for the non-independence of effect sizes. Specifically, the authors implemented a meta-analytic multilevel model that incorporated a variance-covariance matrix in the model (Berkey *et al.*, 1998). This approach allowed the authors to account for the fact that the effects sizes were nested within studies, which in turn improved the ability to estimate the true effect size. The models used an estimate of 0.9 for dependence of effects, informed by expert opinion of the authors. As the exact magnitude of dependence of the effects was unknown, robust variance estimator from the clubSandwich package was used to improve the accuracy of the estimates (Pustejovsky and Tipton, 2022).

In the multivariate model, random effects were added for each effect size within each study, allowing the effect sizes to correlate and have different variances. Parameters of *tau2* and *I2* were used to examine the between-study heterogeneity of the effects (Higgins *et al.*, 2003). Furthermore, as the *Q* statistic for heterogeneity cannot be applied to multilevel models, a likelihood ratio test examining the effect of *tau2* on all outcomes was used as an indicator of significant between-study heterogeneity. The between-study heterogeneity of the effect sizes was indicated if the likelihood ratio test ($\chi 2$) reached a significance level of $p < 0.05$, and the sampling error contributed to the observed variance of less than 75% (Hedges and Olkin, 2014).

The moderators were used in a linear regression analysis as univariate independent variables to explain the possible heterogeneous effects of the outcomes. Interactions of the moderators were not tested because of the lack of statistical significance of the models, low between-study heterogeneity, and inadequate number of effects for certain outcomes (i.e., power) (*Analysing Data and Undertaking Meta-Analyses - Cochrane Handbook for Systematic Reviews of Interventions - Wiley Online Library*, no date). A modified version of Egger's test (Egger *et al.*, 1997) using the standard error of the observed outcomes as a predictor in a multivariate model and a visual examination of the contour-enhanced funnel plots were used to detect publication bias. The presence of outliers and influential studies/effects was analysed using Cook's distance and the distribution of studentized residuals (Viechtbauer and Cheung, no date).

The sensitivity analyses were computed using alternative pre-post correlations in computing the effect sizes as well as examining different autocorrelations in computing the variance-covariance matrix. The results of the sensitivity analysis are listed in Table 10.

The aggregated dataset and R-code used for the analysis can be found on the OSF website (Link). Additional information can be shared on request.

Results

In total, 54 effects from 8 studies were derived for hypertrophy (*k* = 20), power (*k* = 8), and strength (*k* = 26) outcomes. The study selection process from the initial search to final inclusion is shown in Figure 13. The total number of participants was 325 (n=159/166; OCP/naturally-menstruating), with a weighted mean age of 24.0 years. All the included studies investigated the influence of OCPs, with no study including participants using other types of HC. The exercise interventions lasted between 8 and 16 weeks, with a mean duration of 11.1 ±2.5 weeks, and a mean number of 3.5 ±0.5 sessions per week. The mean TESTEX scale score was 9.4, with individual studies ranging from 5 to 13. Individual scores for quality assessment can be found in the Electronic Supplementary Material. The complete descriptive information of the included studies is presented in Table 9.

The interrater agreement statistics support strong agreement between authors. Initially the absolute agreement between the two first authors for all extracted continuous data using the two-way mixed effect model and "single rater" unit for ICC was 0.99 [0.99-0.99], $p < 0.001$. The initial inter-rater reliability for moderator coding was in perfect agreement (unweighted Cohen's Kappa, [2, 330] = 1.00, z = 0, $p < 0.001$, 95% CI = [1.00,1.00]; percent agreement = 100%).

Table 9. Study Characteristics

Study	***n***	**Training Status**	**Intervention Duration (wks)**	**Outcomes**	**Resistance Exercise Training Intervention**	**Study Conclusion**
Dalgaard et al., 2019 (Dalgaard *et al.*, 2019)	OCP -users: 14 Naturally Menstruating: 14	Untrained	10	**Hypertrophy:** MRI: • Vastus Lateralis Muscle CSA Biopsy: • Vastus Lateralis Type I Fibre CSA • Vastus Lateralis Type II Fibre CSA **Strength:** 1RM: • Knee Extension Isokinetic Dynamometer MVIC:	10 weeks of progressive resistance exercise training performed 3 times per week supervised by physical therapists. Training intensities were estimated from the 1 RM test. The exercises consisted of seated knee extensions and inclined leg press performed in a progressive manner; Week 1: 3x 12 repetitions of 15 RM Week 2–3: 3x 12 repetitions of 12 RM Week 4–5: 3x 10 repetitions of 10 RM Weeks 6–10: 4x 10 repetitions of 10 RM.	Use of OCPs was associated with a trend toward a greater increase in muscle mass and a significantly greater increase in type I muscle fibre area compared to controls. Use of OCPs did not influence the overall increase in muscle strength related to training.

					• Knee Extension		
Dalgaard et al., 2022* (Dalgaard *et al.*, 2022)	OCP -users: 20 Naturally Menstruating: 18	Untrained	10		**Hypertrophy:** DEXA: • Fat-Free Mass MRI: • Vastus Lateralis Muscle CSA (10cm) • Vastus Lateralis Muscle CSA (20cm) • Vastus Lateralis Muscle CSA (30cm) Biopsy: • Vastus Lateralis Type I Fibre CSA	10 weeks of supervised resistance exercise training with 3 sessions per week. Four different resistance-training exercises for the legs were performed: Leg press, leg curl, leg extension, and back extension. In addition, 2 upper body exercises were performed: Lat pull down and incline crunch. The length of one training session was 45 minutes. The exercises were performed in a progressive manner as 3–4 sets of 8–12 repetitions, corresponding to their 8–12 repetition maximum. Participants were encouraged to use maximal effort and train near momentary muscle failure. All training sessions were supervised by an exercise therapist. The lifted loads were monitored using individual training logs to ensure subjects adjusted weights throughout the entire training period to maintain muscle loading as muscle strength increased.	The use of a second generation OCP in young untrained women does not promote significantly greater gains in muscle mass or muscle strength compared with nonusers.

				• Vastus Lateralis Type II Fibre CSA **Power:** • Counter-Movement Jump **Strength:** 1RM: • Leg Press Isokinetic Dynamometer MVIC: • Knee Extension • Knee Flexion		
Nichols et al., 2008 (Nichols *et al.*, 2008)	OCP -users: 13 Naturally Menstruating: 18	Trained (NCAA Division 1 Collegiate Athletes)	12	**Strength:** 1RM: • Bench Press 10RM: • Knee Extension Isokinetic Dynamometer Peak Torque:	12-week preseason strength development program. No attempt was made by the researchers to modify the athletes' existing strength training program as designed by the university's strength and conditioning coach. This program consisted of free weight and machine lifting exercises involving the major muscle groups, performed three times per week. Resistance levels were based on percentages ranging from 50% to 80% of initial 1 repetition maximum tests. Individual training logs were	The use of OCPs did not provide sufficient androgenic effect to increase strength gains beyond the stimulus of the training protocol.

				• Bench Press • Knee Extension	maintained to monitor subjects' numbers of sets, repetitions, resistance levels, and program compliance.	
Oxfeldt et al., 2020* (M. Oxfeldt *et al.*, 2020)	OCP -users: 20 Naturally Menstruating: 18	Untrained	10	**Hypertrophy:** Biopsy: • Vastus Lateralis Type I Fibre CSA • Vastus Lateralis Type II Fibre CSA	Same as Dalgaard et al., 2022 (Dalgaard *et al.*, 2022) above.	Use of 2nd generation OCPs in young untrained women increased skeletal muscle MRF4 expression and satellite cell number compared to non-users.
Reichmann and Lee, 2021 (Riechman and Lee, 2022)	OCP -users: 34 Naturally Menstruating: 38	Untrained	10	**Hypertrophy:** Hydrostatic Weighing: • Lean Mass **Strength:** 1RM: • Arm strength (aggregated score) • Leg strength (aggregated score)	10 weeks of resistance exercise training, performed 3 times a week under the supervision of exercise physiologists. The participants performed 3 sets of 6–10 repetitions for each of the following exercises with the resistance set at 75% of each individual's predetermined maximum strength (chest press, incline press, lat pull-down, seated row, shoulder press, leg extension, hamstring curl, triceps extension, arm curl, back extension, and abdominal crunch. weight machines; leg press and calf raises were performed on a Universal leg press machine. The subjects were instructed to perform as many repetitions as possible on every set until they reached muscle failure or achieved 10 repetitions with correct	OC use impairs muscle gains in young healthy untrained women, but the effect may depend on the type of OCPs.

					forms and full range of motion. For every participant, resistance settings were increased when a subject was able to complete 10 repetitions on a particular set. Resistance was adjusted as needed throughout the study according to the results of biweekly reviews of each subject's progression. The resting time was 30 seconds between sets and one minute between exercises.	
Romance et al., 2019 (Romance *et al.*, 2019)	OCP -users: 12 Naturally Menstruating: 11	Trained *(> 2 years continuous resistance exercise training)*	8	**Hypertrophy:** DEXA: • Fat Free Mass **Power:** • Counter-Movement Jump **Strength:** 1RM: • Bench Press • Squat	3-week familiarization period to establish training loads for each exercise, followed by an 8-week intervention period. All subjects performed the same exercises; bench press, barbell row, military press, lat pulldown, incline chest press, biceps curl and triceps pushdown, squat, lunge, leg press, hip thrust, leg extension, lying leg curl and standing calf raise. Subjects completed four training sessions per week. Training sessions were monitored by specialists, adjusting the loads whenever necessary. The lifted loads and perceived exertion in each exercise were monitored by the physical conditioning and strength specialist using a paper tracking form throughout the experiment.	OC use does not impair strength gains nor body composition in resistance-trained young adult women.
Sung et al., 2022 (Sung *et al.*, 2022b)	OCP -users: 34 Naturally Menstruating: 40	Untrained	12	**Hypertrophy:** Ultrasound: • Muscle Thickness (Sum of	12 weeks of submaximal strength training. The initial training value was set to 85% of the maximal isometric strength test, and participants performed 3 sets of 8–12 repetitions on a leg-press machine with 2 min of resting intervals between sets until exhaustion. If any	The effects of RET on muscle strength, muscle thickness, muscle fibre size, and composition were similar in young women irrespective of their OCP use.

		Rectus Femoris, Vastus Lateralis & Vastus Intermedius) Biopsy: • Vastus Lateralis Type I Fibre Muscle Thickness • Vastus Lateralis Type II Fibre Muscle Thickness **Strength:** Combined Force & Load Cell IMVC: • Leg Press	participant was able to perform more than 12 repetitions during a set, they increased the resistance by 10 kg (i.e., 85–95% of their maximal strength) to reduce the number of repetitions to 12 or less. Supervised training was performed 3 times a week using the leg-press machine and once a week at home using the participant's own body weight (squats). For the latter exercise, participants performed 3 sets of 15–20 leg squats with 3–5 min of recovery between sets.

Wikstrom-frisen et al., 2017 (Wikström-Frisén, Boraxbekk and Henriksson-Larsén, 2017b)	**Group 1:** OCP -users: 11 Naturally Menstruating: 8 **Group 2:** OCP -users: 10 Naturally Menstruating: 9 **Group 3:** OCP -users: 11 Naturally Menstruating: 10	Trained *(Mean resistance exercise training experience of 3.5 years)*	16	**Hypertrophy:** DEXA: • Leg Lean Mass • Whole Body Lean Mass **Power:** • Counter Movement Jump • Squat Jump **Strength:** Isokinetic Dynamometer Peak Torque: • Single Leg Knee Extension (Right & Left) • Single Leg Knee Flexion (Right & Left)	In this study of four menstrual/OCP cycles, periodised resistance training refers to high frequency leg training during two weeks of the menstrual cycle. The remaining two weeks of respective cycle the women performed the leg resistance training once a week as part of the training program. In group 1 periodised high frequency training was performed (5 times per week) during the first two weeks of the menstrual cycle. In group 2 periodised high frequency training was performed (5 times per week) during the last two weeks of the menstrual cycle. The women in group 3 trained regularly (3 times per week) during the whole menstrual/OCP cycle. The resistance training in the present study consisted of two exercises, leg press and leg curls, and were started at an individual load. The participants performed double leg press and leg curls three sets of 8-12 repetition maximum (RM) with 1-2 minutes of rest between sets and with 2-10 % increase in load applied when the individual performed the current workload for one or two repetitions over the desired number, according to recommendations to achieve strength gains.6, 7 The women also continued their ordinary training with the exception of leg exercises, which were exchanged to the exercise	High frequency periodised leg resistance training during the first two weeks of the menstrual/OCP cycle was more beneficial in terms of power gain, strength gain and increased leg lean mass compared to high frequency resistance training during the last two weeks.

provided by the researchers. Throughout the study a gym instructor was available to guide the training.

*CSA, cross-sectional area; DEXA, dual-energy X-ray absorptiometry; IMVC, isometric maximal voluntary contraction; RM, repetition maximum. *Shared participants.*

Table 10. Sensitivity Analysis

	Hypertrophy Outcomes						**Power Outcomes**						**Strength Outcomes**					
Sensitivity Analysis Procedure	**ES**	**95% CI**	$\tau^2_{within\text{-}studies}$	$\tau^2_{between\text{-}studies}$	$I^2_{within\text{-}sttdies}$	$I^2_{between\text{-}sttdies}$	**ES**	**95% CI**	$\tau^2_{within\text{-}studies}$	$\tau^2_{between\text{-}studies}$	$I^2_{within\text{-}sttdies}$	$I^2_{between\text{-}sttdies}$	**ES**	**95% CI**	$\tau^2_{within\text{-}studies}$	$\tau^2_{between\text{-}studies}$	$I^2_{within\text{-}sttdies}$	$I^2_{between\text{-}sttdies}$
0.7 Pre-Post Correlation & 0.9 Correlation Matrix	0.01	[-0.11, 0.13]	0.09	0.00	52.28	0.00	-0.04	[-0.93, 0.84]	0.04	0.00	21.30	0.00	0.10	[-0.08, 0.28]	0.03	0.00	18.77	0.00
0.7 Pre-Post Correlation & 0.7 Correlation Matrix	0.01	[-0.12, 0.13]	0.07	0.00	44.15	0.00	-0.04	[-0.91, 0.83]	0.01	0.00	4.51	0.00	0.09	[-0.10, 0.28]	0.01	0.00	5.49	0.00
0.7 Pre-Post Correlation & 0.5 Correlation Matrix	0.01	[-0.13, 0.14]	0.05	0.00	36.40	0.00	-0.04	[-0.92, 0.83]	0.01	0.00	4.51	0.00	0.09	[-0.10, 0.28]	0.01	0.00	5.49	0.00
0.5 Pre-Post Correlation & 0.9 Correlation Matrix	0.00	[-0.12, 0.11]	0.09	0.00	40.66	0.00	-0.06	[-0.96 0.83]	0.03	0.00	12.18	0.00	0.09	[-0.10, 0.29]	0.02	0.00	11.45	0.00
0.5 Pre-Post Correlation & 0.7	0.00	[-0.13, 0.12]	0.06	0.00	30.75	0.00	-0.06	[-0.96, 0.84]	0.00	0.00	0.00	0.00	0.07	[-0.14, 0.28]	0.00	0.00	0.00	0.00

Correlation Matrix																		
0.5 Pre-Post Correlation & 0.5 Correlation Matrix	0.00	[-0.13, 0.13]	0.04	0.00	22.09	0.00	-0.06	[-0.96, 0.84]	0.00	0.00	6.46	3.24	0.07	[-0.14, 0.28]	0.00	0.00	0.00	0.00
0.9 Pre-Post Correlation & 0.9 Correlation Matrix	0.02	[-0.11, 0.15]	0.09	0.00	72.20	0.00	-0.02	[-0.90, 0.87]	0.04	0.00	43.80	0.00	0.11	[-0.06, 0.27]	0.04	0.00	37.56	0.00
0.9 Pre-Post Correlation & 0.7 Correlation Matrix	0.02	[-0.11, 0.15]	0.07	0.00	68.02	0.00	-0.02	[-0.88, 0.84]	0.03	0.00	33.66	2.91	0.10	[-0.07, 0.28]	0.25	0.00	29.66	0.00
0.9 Pre-Post Correlation & 0.5 Correlation Matrix	0.02	[-0.11, 0.16]	0.06	0.00	63.45	0.00	-0.03	[-0.84, 0.79]	0.01	0.01	19.82	9.93	0.10	[-0.08, 0.28]	0.02	0.00	21.11	0.00

Table 11. OCP Types and Menstrual Status Descriptions

Study & *Length of OCP Use*	**OCP Type**	**OCP Brand Name**	**OCP Dosage**	**Non-user Criteria**
Dalgaard et al., 2019 ***(Mean length of OCP use = 6.1 ±5.0 years)***	3rd Generation Combined Monophasic (n= 7)	Lindynette	75 µg gestodene and 30 µg ethinyl oestradiol	n = 14; Had regular menstrual cycles (self-report) for at least 1 year (within the range of 24–35 days).
	3rd Generation Combined Monophasic (n = 5)	Gestonette	75 µg gestodene and 20 µg ethinyl oestradiol	
	3rd Generation Combined Monophasic (n=2)	Novynette	150 µg desogestrel and 20 µg ethinyl oestradiol	
Dalgaard et al., 2022* ***(Mean length of OCP use = 6.5 ±2.5 years)***	2nd Generation Combined Monophasic (n = 17)	Femicept	150 µg levonorgestrel and 30 µg ethinyl oestradiol	n = 18; Had not been using any form of hormonal contraceptive for the past 3 months and reported to that they had experienced a regular menstrual cycle (menses every 24–35 days) at last 3 months or more before the intervention.
	2nd Generation Combined Monophasic (n = 3)	Cilest	250 µg norgestimate and 35 µg ethinyl oestradiol	
Nichols et al., 2008 ***NR***	2nd Generation Combined (n = 13)	NR	NR	n = 18; Had regular menstrual cycles (menses every 25–35 days).
Oxfeldt et al., 2020* ***(Mean length of OCP use = 6.5 ±2.5 years)***	2nd Generation Combined Monophasic (n = 17)	Femicept	150 µg levonorgestrel and 30 µg ethinyl oestradiol	n = 18; Had not been using any form of hormonal contraceptive for the past 3 months and reported to that they had experienced a regular menstrual cycle (menses every 24–35 days) at last 3 months or more before the intervention.
	2nd Generation Combined Monophasic (n = 3)	Cilest	250 µg norgestimate and 35 µg ethinyl oestradiol	
Reichman and Lee, 2021 ***NR***	Oral contraceptives (n = 34)	Orthotricycle, Orthonovum, Orthocept, Desogen, Nordette, Alesse, Tivora, Estrostep, Loestrin	NR	n = 38; No information was available on the menstrual status of non-OCP users.
Romance et al., 2019 ***NR***	2nd Generation (n=4)	NR	150 µg levonorgestrel and 30 µg ethinyl oestradiol	n = 11; Had reported to have regular menstrual cycles (i.e., occurring on a 28- to 30-day cycle) and had not taken any form of synthetic oestrogen or progesterone for at least six months prior to the study.
	3rd Generation (n=8)	NR	50 µg gestodene and 30 µg ethinyl oestradiol	

Sung et al., 2022 ***(OCP use of ≥ 1 year prior to study)***	2nd Generation Combined Monophasic (n= 3)	Anastrella 28	150 µg levonorgestrel and 30 µg ethinyl oestradiol	n = 40; Had no OCP use or hormonal treatment in the past year. Two months of monitoring daily body temperature were performed to establish regularity of menstrual cycle prior to beginning intervention. Mean menstrual cycle length throughout intervention = 28.2 ±1.2 days.
	2nd Generation Combined Monophasic (n=10)	Cilest	250 µg norgestimate and 35 µg ethinyl oestradiol	
	2nd Generation Combined Monophasic (n=8)	Femicept	150 µg levonorgestrel and 30 µg ethinyl oestradiol	
	2nd Generation Combined Monophasic (n= 9)	Loette	100 µg levonorgestrel and 20 µg ethinyl oestradiol	
	2nd Generation Combined Monophasic (n=4)	Microstad	150 µg levonorgestrel and 30 µg ethinyl oestradiol	
Wikstrom-Frisen et al., 2017 ***NR***	Combined Monophasic (n = 11)	NR	NR	n = 44; Had a regular menstrual cycle of 28 days (acceptable 21-35 days).
	Combined Triphasic (n = 20)	NR	NR	

**Shared participants. NR = not reported*

Hypertrophy Outcomes

For hypertrophy outcomes, 65% of the outcome estimates were positive (favouring the OCP condition), ranging from −0.39 to 1.25. The multivariate model indicated that the standardised mean change difference between the conditions was 0.01 (CI 95% [-0.11, 0.13], $t = 0.14$, $p = 0.90$). The standardised mean change difference did not differ significantly from zero and showed no evidence of between study heterogeneity ($\chi^2(1) = 0.00$, $p = 1.00$, $\tau^2_{between\text{-}studies} = 0.00$, $\tau^2_{within\text{-}studies} = 0.09$, $I^2_{between\text{-}studies} = 0\%$,, $I^2_{within\text{-}studies} = 52.3\%$).

The effect sizes aggregated at the study level (one effect per study displayed per outcome) and their CIs, as well as the standardised mean change difference according to a meta-analytic multivariate model and two-level random effects model, are displayed in Figure 14.

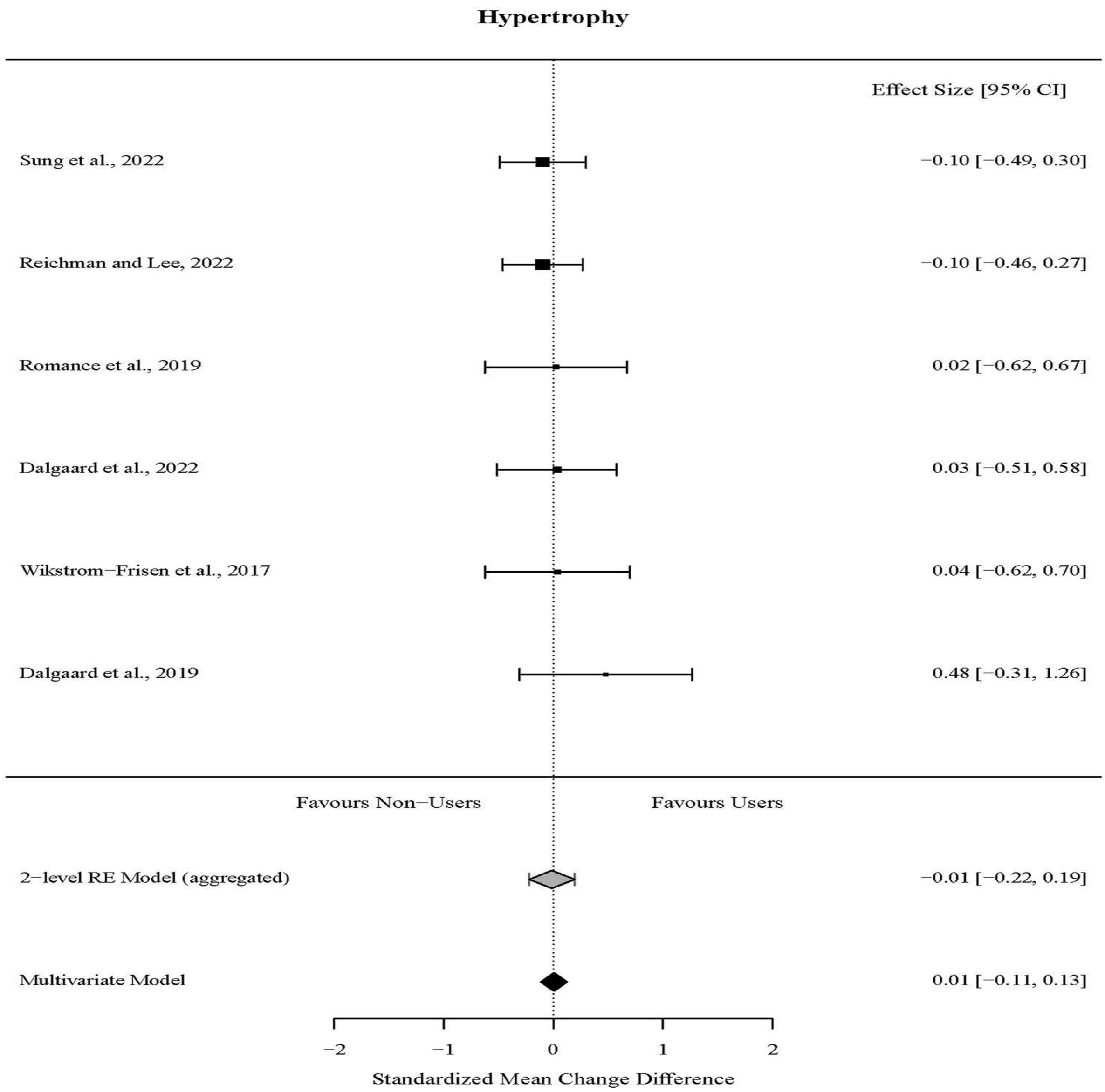

Figure 13. Forest plot of hypertrophy outcomes

Power Outcomes

For power outcomes, 37.5% of the outcome estimates were positive (favouring the OCP condition), ranging from −0.47 to 0.38. The multivariate model indicated that the standardised mean change difference between the conditions was -0.04 (CI 95% [-0.93, 0.84], t =*-0.29, p* = 0.80). The standardised mean change difference did not differ significantly from zero and there was no between-study heterogeneity ($\chi^2(1) = 0.00$, $p = 1.00$, $\tau^2_{between\text{-}studies} = 0.00$, $\tau^2_{within\text{-}studies} = 0.04$, $I^2_{between\text{-}studies} = 0\%$,,

$I^2_{within\text{-}studies}$ = 21.3%). The effect sizes aggregated at the study level (one effect per study displayed per outcome) and their CIs, as well as the standardised mean change difference according to a meta-analytic multivariate model and two-level random effects model, are displayed in Figure 15.

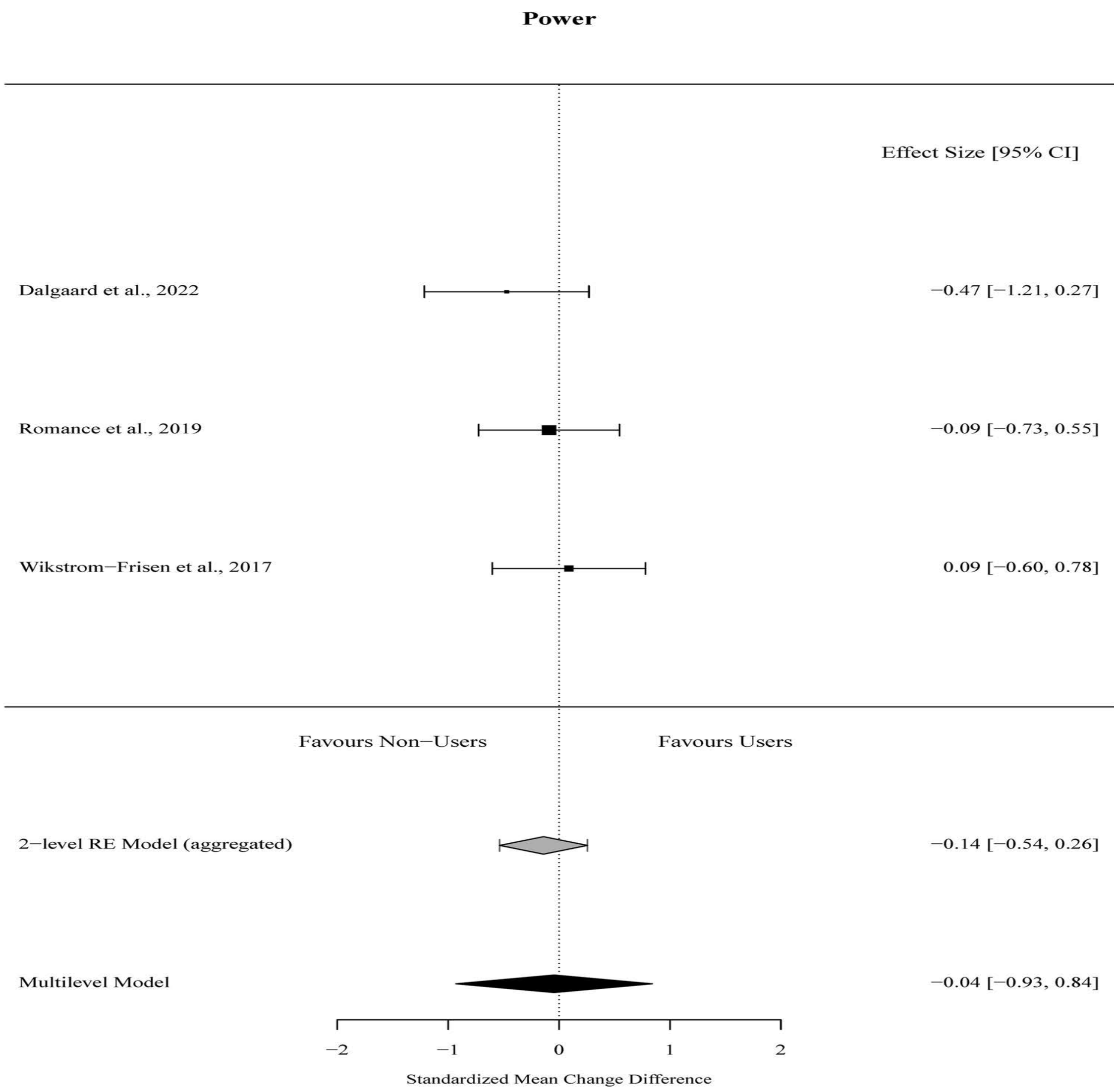

Figure 14. Forest Plot of Power Outcomes

Strength Outcomes

For strength outcomes, 62% of the outcome estimates were positive (favouring the OCP condition), ranging from −0.35 to 0.62. The multivariate model indicated that the standardised mean change difference between the conditions was 0.10 (CI 95% [-0.08, 0.28], t =*1.48, p* = 0.20). The standardised mean change difference did not differ significantly from zero and showed no between-study heterogeneity ($\chi^2(1) = 0.00$, $p = 1.00$, $\tau^2_{between\text{-}studies} = 0.00$, $\tau^2_{within\text{-}studies} = 0.03$, $I^2_{between\text{-}studies} = 0\%$,, $I^2_{within\text{-}studies} = 18.8\%$). The effect sizes aggregated at the study level (one effect per study displayed per outcome) and their CIs, as well as the standardised mean change difference according to a meta-analytic multivariate model and two-level random effects model, are displayed in Figure 16.

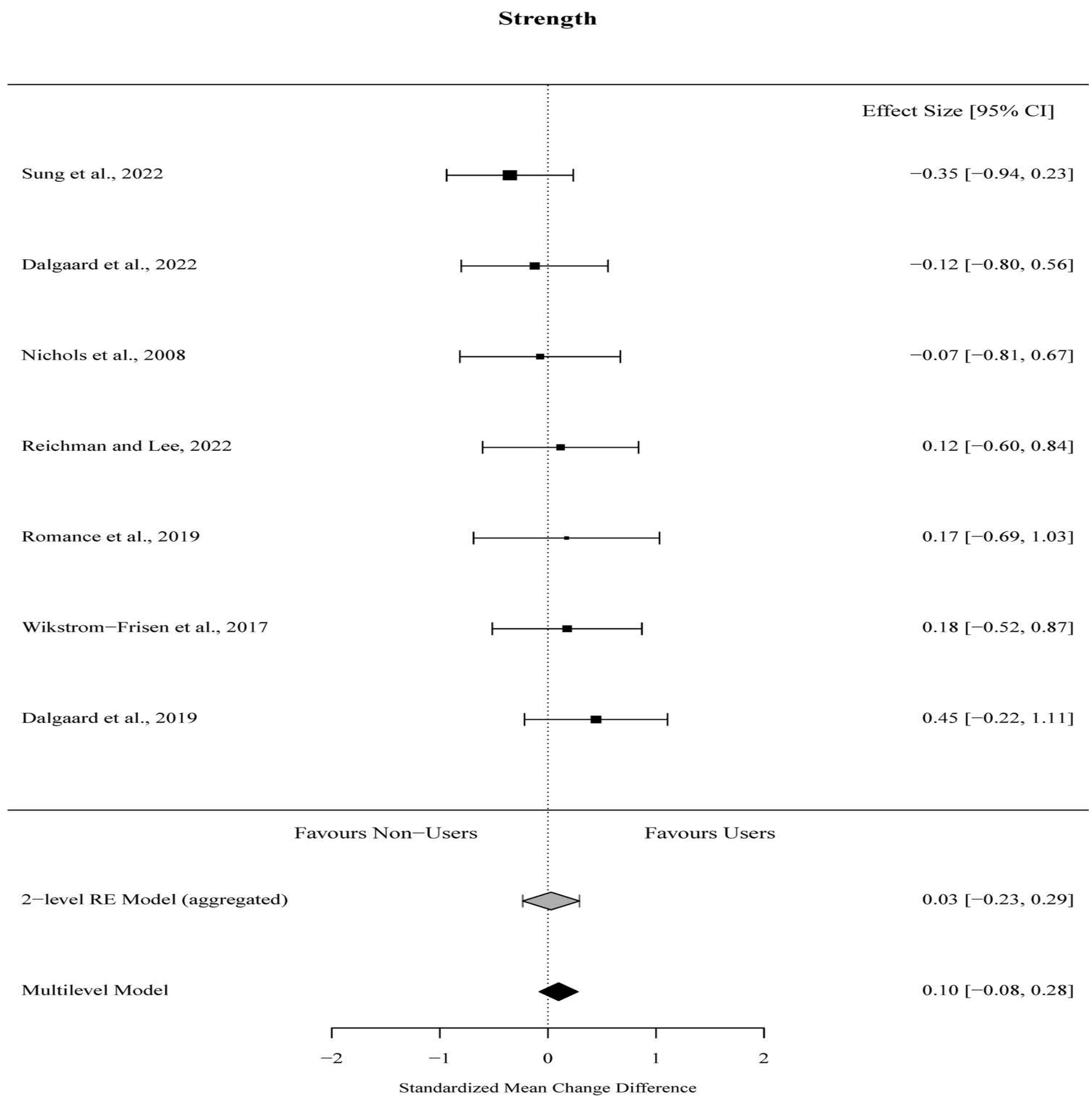

Figure 15. Forest plot of strength outcomes

Discussion

This is the first meta-analysis to investigate the influence of HC use on skeletal muscle hypertrophy, power, and strength adaptations in response to resistance exercise training, and found that OCP use had no statistically significant effect on any of these adaptations. Based on the current analysis, there is no evidence-based rationale to advocate for or against the use of OCPs in females partaking in resistance exercise training to increase hypertrophy, power, and/or strength, nor is there evidence that HC use would attenuate these adaptations. Rather, an individualised approach, considering an individual's response to OCPs, and their reason(s) for use may be more appropriate.

There are several suggested mechanisms by which sex hormones may influence adaptations to resistance exercise training. OCPs downregulate the endocrine production of the primary ovarian hormones i.e., oestrogen and progesterone. While oestrogen may influence pathways and processes which influence muscular adaptations to resistance exercise training (i.e., protein turnover, myosin function, and satellite cell activity), its role in the regulation of muscle mass is unclear, and potential mechanisms mediated by progesterone are largely unknown (Colenso-Semple *et al.*, 2023). Oestrogen likely plays a role in modulating protein synthesis/degradation pathways, with differing protein synthesis rates observed in post-menopausal females undergoing oestrogen replacement therapy, compared to those not undergoing hormone replacement therapy (Hansen *et al.*, 2012; Dam *et al.*, 2020). Oestrogen may influence muscle strength, via its influence on myosin proteins, as demonstrated by oestrogen deficiency (observed in rodent models and during menopause), negatively impacting the structure-function relation of myosin and actin during activity, reducing force-generating capacity, and increasing fatiguability (Pellegrino, Tiidus and Vandenboom, 2022). Oestrogen may also influence satellite cell activity and function by modulating paired box homeotic gene 7 (a marker of satellite cell number), myogenic differentiation factor D-positive fibres, and DNA uptake of bromo-deoxyuridine, yet this is predominantly shown in ovariectomised rodent models receiving oestrogen replacement (Oosthuyse, Strauss and Hackney, 2023), and further study in human subjects is warranted. It could be argued, given the potentially different hormonal profile experienced by OCP users, that is, downregulated endogenous levels of oestrogen and progesterone, that OCP users may not benefit from theoretical positive benefits of endogenous oestrogen for skeletal muscle adaptations to resistance exercise training. However, the current analysis does not support this hypothesis.

Some methodological considerations that are important to contextualise the findings of this study warrant further discussion. The average study duration was 12.3 weeks, yet increasing lean body mass through targeted interventions is a relatively slow process compared to muscular strength. On average, muscular strength increases by 25% in females following 15-weeks of resistance exercise training, while lean body mass increases by 3.3% (1.4 kg) in the same period (Hagstrom *et al.*, 2020). Differences in skeletal muscle hypertrophy, if any, between OCP users and non-users may require a longer time course to manifest than has been studied to date. Studies had relatively small sample sizes (mean n=45; range 28-74), with mean group sizes of 17 across all measures. Larger sample sizes may be warranted in future studies, as the magnitude of response to resistance exercise training varies extensively between individuals for both hypertrophy (-11 to 30%) and strength (-8 to 60%) outcomes (Ahtiainen *et al.*, 2016). Only three of the studies that met the inclusion criteria reported power outcomes (all lower body), providing only 8 effects, resulting in the meta-analysis model reported likely being underpowered for this outcome measure, evident by the wide confidence interval reported. Therefore, the results of the meta-analysis of the power outcomes should be interpreted with caution. Several studies grouped participants using various brands (differing formulations and dosages), and in some cases, differing generations (differing progestin components). Grouping participants using different types of OCP results in various concentrations of endogenous sex hormones and could result in non-homogenous participant groups (Elliott-Sale *et al.*, 2013). As the potential impact, if any, of HCs on adaptation are likely mediated predominantly by the oestrogenic component, grouping participants using OCPs of differing dosages, androgenicity, or using progestin-only pills is problematic. Genetic variations in tissue-specific oestrogen sensitivity also exist which may confound any potential influence of different contraceptive types (Wall *et al.*, 2014).

OCPs are used not only to prevent pregnancy, but for multiple reasons, such as in athletes for the alleviation of menstrual-related symptomatology and manipulation of the bleeding phase (Bennell, White and Crossley, 1999; Schaumberg *et al.*, 2018). Negative menstrual cycle symptomology is often reported as a barrier to engaging in exercise training, resulting in reduced training frequency, intensity, and volume (Bruinvels *et al.*, 2020). One speculation could be that if OCP use was to reduce the negative menstrual-related symptomatology, resistance exercise training adaptations may be enhanced in these individuals by facilitating completion of higher frequencies, intensities, and volume of training. However, as evidenced in chapter 4 it is not uncommon for HC users to report negative symptomology relating to HC use. Therefore, it may not be a ubiquitous method to enhance training performance in those experience negative menstrual related symptomology. Based on the current analysis, it must be stressed that at present there is no evidence-based rationale to advocate or oppose the use of OCPs in females participating in resistance exercise training to increase hypertrophy, power, and/or strength.

Future research should consider longitudinal analysis using sufficient sample sizes to account for large variability in exercise response (Ross *et al.*, 2019), as differences, if any, between HC users and non-users may take considerable time to manifest, particularly for hypertrophy. The presently available studies investigating the influence of HCs on adaptations to resistance exercise training have exclusively investigated OCPs. Research should also examine the potential influence of different HC types (injection, intrauterine devices, implants, etc.), which result in differing hormonal profiles, on adaptations to resistance exercise training. In future investigations examining the influence of OCPs specifically, appropriate levels of detail describing the type of OCP and providing appropriate biochemical outcomes, such as blood samples, are needed to confirm the hormonal profiles of OCP users and non-users, as previously advocated (Janse DE Jonge, Thompson and Han, 2019; Elliott-Sale *et al.*, 2020). However, current blood analysis techniques only measure endogenous oestradiol levels, and do not allow for appropriate measurement of exogenous synthetic ethinyl oestradiol (Cirrincione *et al.*, 2022). Future research should also ensure intervention groups are appropriately designed to minimise the grouping of OCP users who use different OCP types and dosages, or adequately account for these subgroup differences in their statistical analysis. The impact, if any, of HC and OCPs on power-related adaptations are understudied and warrant further investigation.

Conclusion

To the authors knowledge, this is the first systematic review and meta-analysis to conduct a between-group comparison of skeletal muscle hypertrophy, power, and strength adaptations to resistance exercise training in HC users and non-users. This systematic review with meta-analysis showed that OCPs were the only HC studied to date, and OCP use had no statistically significant effect on these adaptations in response to resistance exercise training. As such, these data suggest that OCP use does not positively or negatively influence hypertrophy, power, or strength adaptations in females partaking in resistance exercise training.

Chapter 8 – Main Findings & Conclusion

Main Findings

Upon embarking on this PhD in the summer of 2019, there was a discernible dearth of literature focused on physical preparation in women's rugby union. Notably, no studies had investigated aspects such as coaching practices, menstrual cycle symptomatology, or the prevalence of HC usage in this demographic. For instance, a PubMed query employing the search string "women's rugby" OR "female rugby", up until 1st April 2019 yielded a mere 56 results. Four years later, the research field has expanded significantly, with 92 additional articles published in the subsequent period from April 2019 to May 2023. Despite this increase in the number of publications, further research is necessary, particularly regarding physical preparation as I estimate <5% of the ~150 aforementioned studies relate to physical preparation strategies in women's rugby union. This PhD thesis has made several original contributions, thereby advancing the body of knowledge in this field. The primary findings and implications for practice from each results chapter of this dissertation are concisely summarised in the subsequent sections.

Study 1

This study provides important insights and contextual evidence for the understanding of sex-specific considerations in the physical preparation of female rugby players from the perspective of elite-level strength coaches, which, to date, has not been explored.

In the opinion of the coaches interviewed, women's rugby is of a lower standard than men's rugby in terms of 'elite' status and professionalism. Coaches highlighted that international female players often presented with low technical ability and training age in gym-based movements due to a lack of systematic support within their performance environment and developmental pathways.

Overall, while coaches were of the opinion that there are some female-specific considerations regarding physical preparation that they are cognisant of i.e., individual management of menstrual cycle symptoms, there was no meaningful difference in how they approached the physical preparation of females compared to males in terms of training methodologies. Differences in approaches to physical preparation are primarily driven by lower training age and poorer technical ability of female athletes compared to males, rather than distinct anatomical or physiological differences, a potential legacy of under-resourced developmental pathways, and support structures for female rugby players.

There were clear gaps in the knowledge exhibited by the coaches regarding both the menstrual cycle and hormonal contraceptives. Educational programs aimed at enhancing coach knowledge in this domain may be advisable.

The coaches clearly strive to utilise an evidence-based approach where and when possible but often lack the necessary support or information to do so. Informal resources (i.e. social media and podcasts) and colleagues were identified as the primary sources of education that the coaches utilised. There was a perception among the coaches that empirical data in elite female athletes are practically non-existent, a misconception which may require addressing in this population. Educational interventions in these cohorts may be beneficial, particularly if delivered via already accepted mediums e.g., podcasts.

Study 2

This study provides important insights and contextual evidence for understanding between-sex differences in interpersonal relationships with rugby players from the perspective of elite-level strength coaches.

Differences in psychosocial factors, such as communication and social dynamic characteristics, may lead to different barriers to engagement between male and female athletes. Evidence examining between-sex differences in interpersonal characteristics is equivocal demonstrating a high degree of individual variability amongst participants. Despite this, the coaches in this study consistently reported distinct perceived differences between male and female players regarding interpersonal characteristics. Practitioners should be aware of these potential differences and further research is required to determine what constitutes effective communication strategies to ensure that successful relationships are developed with athletes. Practitioners should be highly cognisant of professional boundaries and place athlete welfare as paramount at all times.

Study 3

This study investigated the prevalence of menstrual cycle symptomology, HC use and HC side-effects in a cohort of rugby and powerlifting athletes.

Current HC use was reported by 51.1% of athletes, with similar prevalence for the two sports (powerlifting, 48.3% vs. rugby, 54.1%). The side effects of the menstrual cycle were reported in 83.5% of non-HC users, with the most common being unspecified cramping (42.4%), headache/migraine (24.5%), and fatigue (24.5%). Side effects were reported in 40.0% of HC users, with the most common being mood changes (17.9%), stomach pain (8.3%) and headaches/migraines (6.9%). A large proportion of HC users and non-users in this study experienced negative side effects of HC use and menstrual cycle, respectively. The symptoms experienced by both groups were wide-ranging, with a high degree of variation between individuals. The data presented in this study highlight the importance for athletes and coaches to have an open dialogue regarding menstrual cycle function and HC use. Both HC and non-HC users experience negative side-effects, which may have an influence on performance in training and competition . I recommend that coaches adopt an accommodating culture in which flexibility may be permitted to accommodate for those athletes experiencing severe symptoms of the menstrual cycle or HC use.

Study 4

This study provided the descriptive data of the physical demands of match play from an elite, amateur, women's international rugby union team competing in the Women's Six Nations Championship across a three-year period. The total running demands were similar to those previously reported in other international cohorts employing a similar methodology; however, the number of collisions per minute was higher than that previously reported in similar cohorts. Differences in physical demands were found between positions, and these data will inform practitioners of the broad demands of match play and position-specific differences, which will aid in the designing of physical preparation training programmes.

Study 5

This systematic review and meta-analysis conducted a between-group comparison of young males and females to quantify baseline differences in hypertrophy, power, and strength in untrained individuals, and examined differences in response to resistance exercise training for hypertrophy, power, and strength outcomes. Significant baseline differences between males and females were reported for fat-free mass, upper body strength, and lower body strength. In response to resistance exercise training, similar effect sizes were observed between males and females for hypertrophy and lower body strength outcomes, with a greater magnitude of effect for females reported for upper body strength. Differences in muscular power were not examined because of an insufficient number of effects. These analyses would suggest that there are meaningful differences in anthropometric and physical performance characteristics between untrained males and females; however, males and females respond in a similar manner to resistance exercise training for hypertrophy and lower body strength, with females displaying a greater magnitude of effect in upper body strength. Based on this analysis, practitioners should not expect males and females to display a meaningful divergent response to similar resistance exercise training protocols. Consequently, there appears to be no rationale to suggest that females require differing resistance exercise protocols to elicit increases in skeletal muscle hypertrophy or strength.

Study 6

To my knowledge, this is the first systematic review and meta-analysis to conduct a between-group comparison of skeletal muscle hypertrophy, power, and strength adaptations to resistance exercise training in HC users and non-users. This systematic review with meta-analysis showed that OCPs were the only HC studied to date, and OCP use had no statistically significant effect on these adaptations in response to resistance exercise training. These data suggest that OCP use does not positively or negatively influence hypertrophy, power, or strength adaptations in females participating in resistance exercise training. Based on this analysis, there is no evidence-based rationale for practitioners to advocate or oppose the use of OCPs in females participating in resistance exercise training to increase hypertrophy, power, and/or strength.

Current Research and Future Directions

Attitudes Beliefs and Practices of Elite Level Strength and Conditioning Coaches Towards Physical Preparation in Women's Rugby Union

In this dissertation, I present evidence illustrating that elite strength and conditioning coaches working with international-level women's rugby union teams appear to adopt an androcentric perspective on physical preparation. In other words, they predominantly incorporate practices extrapolated from and compare their female athletes to their male counterparts in sports. One might posit that this phenomenon could be attributed to the predominance of male coaches, as 75% of our interview participants were men. However, it is contended here that this sample is, at a minimum, representative of the broader industry and might, in fact, afford an overrepresentation. According to estimates drawn from data in the UK and North America, women comprise only approximately 7-16% of strength and conditioning coaches (Thomas, Devine and Molnár, 2022).

The predominance of an androcentric perspective is most likely attributable to a combination of factors: notably, the coaches' previous experience were predominantly with male teams and they had a shared perception that empirical data pertaining to female athletes is sparse or non-existent. Despite the arguable underrepresentation of females in sports science literature (Costello, Bieuzen and Bleakley, 2014; Cowley *et al.*, 2021), they nonetheless constitute approximately one-third of all sports science participants, a proportion that arguably provides a substantive body of literature from which practitioners could draw meaningful inferences. In the domain of women's rugby union, the volume of studies is admittedly lower compared to their male counterparts, yet to label it as non-existent is misleading. More than 140 studies relevant to sports science have been published (Heyward *et al.*, 2022).

Admittedly, research relating to elite-level athletes is far fewer in number, but this is an issue across both sexes and is not just specific to females. Evidence-based practice has been and remains an issue in elite performance realms (Coutts, 2017). By definition, "elite" represents a small subsection of any given population, and carrying out research with such cohorts presents formidable obstacles, including logistical hurdles, access issues, and constraints on autonomy. Interventional-based research is especially challenging, rendering the majority of studies conducted with elite cohorts to rely primarily on case study, retrospective, and cross-sectional research designs (Burgess, 2017). The inferences that practitioners can draw from research conducted on sub-elite and recreational athletes are inherently limited. Therefore, when working with elite cohorts, adopting an "evidence-informed" rather than an "evidence-based" approach may be more judicious. Such an approach integrates scientific principles and current research consensus into the design and implementation of physical preparation programs while acknowledging that these elite cohorts likely represent outlier populations with characteristics divergent from the majority of research study participants (Coutts, 2017).

As such, practitioners might find it advantageous to adopt a degree of flexibility and experimentation in their approaches, based on personal experience, observations, and the qualitative insights offered by their athletes regarding their training history. An approach that amalgamates scientific principles (grounded in a comprehensive body of research evidence, while acknowledging its limitations), practitioner expertise gleaned through experiential observations, and athletes' beliefs and preferences more accurately reflects the true essence of evidence-based practice as originally conceptualised in the medical literature (Thoma and Eaves, 2015), that is, the triangulation of clinical expertise, best research evidence, and patient values/preferences.

A similar approach might be appropriate when considering between-sex disparities pertaining to the technical facets of physical preparation and interpersonal dynamics of the athlete-coach relationship. While group-level variances between males and females are observable in physical and interpersonal attributes, substantial within-sex diversity is also present. From a practical standpoint, this indicates that while understanding sex-level average distinctions may hold importance for practitioners, recognition of the wide spectrum of variability within sexes and across the overall population may be more relevant. It would be misguided for coaches to apply specific physical preparation strategies based solely on the athlete's biological sex. Instead, the focus should be on coaching the "individual" athlete, adhering to a first-principles approach. This strategy necessitates the design of interventions grounded in an individualised needs analysis. While the athlete's biological sex represents a significant factor, it should not be considered as the definitive determinant guiding interventional decisions. Rather, the strategy should embrace the complexity of individual differences and consider a broad range of factors that influence each athlete's unique performance capacity.

The Menstrual Cycle

The coaches interviewed in this thesis highlighted the research areas related to the influence of the menstrual cycle on performance and injury as being of interest in guiding their future practices while also highlighting a clear lack of awareness related to hormonal contraceptive use in athletic populations and their possible influences. To date, the body of literature presents a paradox in which subjective self-report data from athletic populations (as shown in this thesis) report a high proportion of sportswomen experiencing negative symptomology related to their menstrual cycle which they perceive to have a deleterious influence on their performance (Martin *et al.*, 2018b; Findlay *et al.*, 2020; Nolan, Elliott-Sale and Egan, 2023). However, the totality of the evidence examining the influence of the menstrual cycle using objective measures shows no influence of menstrual cycle phase on physical performance (McNulty *et al.*, 2020; Colenso-Semple *et al.*, 2023).

This paradox presents the practitioner with clear difficulty in interpreting and applying the current body of evidence. When objectively measured, neuromuscular function appears to not be significantly influenced by the menstrual cycle phase, yet the lived experience of athletes would contradict this. This presents the possibility that the influence of menstrual cycle phase is due to the fluctuating hormonal milieu affecting psychological processes rather than being a purely physiological mechanism, however I stress that it is naïve to view systems in the body in a mutually exclusive fashion, as physiology influences psychology and vice versa. The menstrual cycle phase i.e., early-follicular compared with late-follicular and late-luteal phases, has been shown to augments the rate of perceived exertion and pain tolerance for a fixed workload (Hooper, Bryan and Eaton, 2011; Prado *et al.*, 2021). It may be the case that while menstrual cycle phase does not significantly influence neuromuscular function, it may simply influence perceived effort for any given intensity. In other words, while female athletes may generate similar skeletal muscle performance characteristics across different menstrual cycle phases, producing the same force output may be subjectively more challenging during certain menstrual cycle phases. This perspective should not be misconstrued as dismissively asserting that the menstrual cycle's impact is merely psychological, or as a supercilious academic asserting that the true impact of the menstrual cycle is “just in their heads”. From a practical standpoint, if executing an identical workload feels more strenuous at a particular time, then, for all intents and purposes, it is more challenging, given that this is the athlete's lived reality. Performance and the capacity to maintain high levels of effort in both training and competitive environments are determined by a complex interaction of biological, psychological, and social factors rather than being purely determined by physiological factors.

This paradox may also be explained in part by the poor quality of the studies completed to date with small sample sizes and clear methodological flaws (i.e. lack of appropriate controls and lack of blood sample confirmation of hormonal status). It may simply be a case that the poor quality of studies has limited our ability to detect a modifying effect of the menstrual cycle phase on performance that does indeed exist i.e. a type II error, and the advent of higher-quality studies may report findings that contradict the current body of evidence.

Although I advocate for, and align with, the call for enhanced research concerning the role of the menstrual cycle in performance (Colenso-Semple *et al.*, 2023), I propose a counterargument suggesting that an overemphasis on menstrual cycle research may serve as a diversion, with a probable key contributor to the aforementioned paradox underpinning my argument. Current research has not identified a consistent, significant impact of menstrual cycle phase on objective physical performance measures. However, this research has predominantly endeavoured to compare one phase, such as the follicular phase, with another, such as the luteal phase, seeking statistically significant differences at the group level. This approach may be problematic when acknowledging that the influence of the menstrual cycle on physiological processes exhibits substantial inter-(differences between individuals) and intra-individual (cycle-to-cycle differences) variability (McNulty, Hicks and Ansdell, 2021).

The pronounced degree of variance, as reflected in athletes' lived experiences and substantiated by the high prevalence of deleterious menstrual cycle symptomology reported in this thesis and in other studies, underscores the heterogeneity observed in this research area. Given such inter- and intra-individual variability, it appears improbable that research will converge on consensus guidelines for population-level adaptations of physical training according to menstrual cycle phases. This raises the question of the judicious allocation of resources towards menstrual cycle-centric research if the primary objective of sports science research is to enhance athletic performance and support practitioners. While it is valid to critique the majority of existing research in this field as subpar, necessitating additional high-quality investigations, we must introspect: What impact do we expect these studies to yield?

As a thought experiment, if we envisage the "perfect" study investigating the influence of menstrual cycle phase on performance, complete with an adequately large and representative sample size, rigorous control of confounding variables, data collection over multiple cycles, and confirmation of menstrual cycle phase through longitudinal tracking and biochemical analysis, what outcome would we predict? Would we anticipate a uniform group-level effect of menstrual phase on physical performance, for example, with performance consistently reduced in the luteal phase across all participants? Or would we expect that while certain trends might be discernible, there would be significant inter-individual variability, with performance reductions being individual-specific and inconsistent, and considerable intra-individual variability, that is, the magnitude of effect varied from cycle to cycle and was not consistent in a sizeable proportion of the individuals.

My opinion is that the latter scenario appears more plausible. Given the formidable feasibility challenges and resources required to execute this "perfect" study, we must consider the implications of such a finding for practitioners. Given the extent of between- and within-athlete variability, the most pragmatic recommendations for practitioners would likely consist of the following: 1) longitudinal data collection relevant to the individual athlete (incorporating both objective and subjective data related to menstrual cycle, performance, lifestyle, etc.), 2) identification of discernible trends or patterns in the data, if any, and 3) implementation of individualised intervention or coping strategies as necessary, informed by personal experience, best research evidence, and athlete preference. This three-step process, which I argue the literature would ultimately advocate for, essentially embodies the coaching process. Consequently, I question the potential real-world impact of directing substantial focus and resources towards investigating the effect of menstrual cycle phase on physical performance. I contend that although this may be academically fulfilling, it may have little translational value for practitioners and sportswomen.

An examination of the potential influence of the menstrual cycle from a biopsychosocial perspective, recognising the pronounced variability, might be pivotal for the future impact of this research field. Perhaps, a more intriguing and potentially impactful research question pertains to the factors that explain this variability. Why are certain female athletes affected more than others while some experience no discernible deleterious effects? This understanding could guide the development of interventions that target and alleviate negative symptoms associated with the menstrual cycle.

Moreover, it is worth considering whether excessive focus on the menstrual cycle and advocacy campaigns promoting greater awareness of menstrual cycles in sports could inadvertently affect athletic performance. I have previously addressed how athlete beliefs can significantly influence performance, and it is crucial that we, as practitioners, do not unintentionally affect performance through well-intentioned menstrual-related athlete education interventions. Informing athletes about the potential negative effects of the menstrual cycle on physical performance could arguably foster a psychosocial environment that produces an expectancy effect (Aubuchon and Calhoun, 1985; Olasov and Jackson, 1987). This could inadvertently lead to a nocebo effect, where athletes, expecting worse outcomes due to their menstrual cycle, engage in a self-fulfilling prophecy that negatively impacts their performance (Hurst *et al.*, 2020; Raglin *et al.*, 2020).

As academics and practitioners, we must exercise caution in our communication to avoid instigating such expectancy effects in our athletes. Instead, we should continue to advocate for individualised approaches when considering the interactions between the menstrual cycle and athletic performance.

As shown through the opinion of the coaches interviewed in this thesis, there is a perception that female athletes are not supported to the same extent as their male counterparts, and female athletes, on average, have lower physical preparation training than male players at the same competitive and age grade. Further research investigating these systemic inequalities, attitudes, and beliefs of governing bodies towards physical preparation for female athletes and examining the effect of implementing physical preparation programs akin to what male players are afforded would arguably have more of an impact on improving physical performance and reducing injury in women's rugby union, and in female athletes generally, than further research exploring menstrual-specific issues.

Hormonal Contraceptives

Hyper-fixation on the menstrual cycle also neglects approximately half of female athletes who do not have a menstrual cycle, with 51% of athletes using HCs as shown in this thesis and consistent with other studies in differing cohorts (Martin *et al.*, 2018b; Bruinvels *et al.*, 2020), with OCP being the most common form of HC used. Understanding the potential influence of HCs on physical performance and adaptation may have important implications for practitioners. Theoretically, the chronic downregulation of endogenous oestrogen and progesterone production caused by OCPs may impact performance and adaptation to physical training, as discussed previously in this thesis. However, the current body of evidence does not suggest that OCP use has a significant impact on physical performance measures (Elliott-Sale *et al.*, 2020). Prior to the meta-analysis undertaken in this thesis, evidence regarding the potential influence of HC use on adaptation to resistance exercise training was equivocal. This thesis showed that OCP does not appear to have a significant influence on skeletal muscle hypertrophy, power, or strength adaptations in response to resistance exercise training. Based on our analysis, practitioners should be aware that there is currently no evidence-based rationale to advocate for or advise against the use of OCPs in females engaging in resistance exercise training.

The methodological issues identified within the studies included in our analysis necessitate further investigation in this research area. As discussed in detail earlier in this thesis, the grouping of participants using differing formulations of OCP is likely to result in greater heterogeneity within a given OCP group, potentially constraining the ability to detect group level differences in statistical analyses compared to non-HC users. Additionally, the absence of appropriate biochemical analysis of blood samples limits our ability to fully understand the hormonal milieu of participants in these studies. That said, there appears to be no current valid analysis method for measuring concentrations of exogenously administered oestradiol or progesterone from OCPs, with existing methods only capable of measuring endogenous production (Cirrincione *et al.*, 2022). Consequently, researchers must presupposition the hormonal environment of HC users. The development of suitable analytical methodologies to measure concentrations of exogenously administered oestradiol and progesterone might enable increased rigour and facilitate the exploration of potential mechanisms underlying the influence of OCPs on adaptations to exercise. However, it should also be noted that ethinyl oestradiol, the most commonly used oestrogenic component in OCP's is not "bioidentical" to 17 beta oestradiol, that is, they differ in their chemical and molecular structure (Liu *et al.*, 2022). Therefore, even if it were possible to accurately measure exogenous oestrogen concentrations, we cannot necessarily infer what effect it may have based on our current understanding of endogenous regulation.

Regarding HCs and exercise performance and adaptation, the majority, if not all, of relevant research has examined OCPs. Future research should explore different forms of contraceptives and their potential influences. Anecdotally, athletes often experiment with different formulations and types of HC and experience different side effects depending on the type and formulation of HC. Interestingly, the influence of OCPs on adaptations in power-related outcome measures have not been studied to any great degree, if at all. Power is a key performance determinant in many sports (Comfort *et al.*, 2018); thus, future research is warranted.

Between-sex Differences in Hypertrophy and Strength Adaptations to Resistance Exercise Training

This thesis has clearly shown and quantified differences between untrained males and females at baseline in fat-free mass, upper-body strength, and lower body strength. Interestingly, despite the differences in baseline characteristics, no differences were found in hypertrophy or lower-body strength outcomes in response to matched resistance exercise training. A greater magnitude of effect for females was found for upper-body strength outcomes, with potential reasons for this discussed in detail earlier in this thesis. The majority of the included studies measured absolute changes in the outcome measures and failed to apply allometric scaling, that is, to make the outcome measures relative to height and/or body mass. Relative strength is arguably more important than absolute strength (Loturco *et al.*, 2021). Future research should report both absolute and relative measures in their analysis or, at the very least, make available participant-level data via online repositories to enable replication and/or meta-analysis.

The similar responses observed between males and females following matched resistance training exercise again raises the question regarding the influence of endogenous sex hormones in the regulation of skeletal muscle hypertrophy and strength adaptations. While there are clear mechanisms by which testosterone and oestrogen may influence skeletal muscle regulation in males and females (Kim *et al.*, 2016; Gharahdaghi *et al.*, 2021; Alexander, Pollock and Lamon, 2022), respectively, whether acute fluctuations within *normal physiological* ranges exert a meaningful impact on the adaptive response to resistance exercise training is unclear. Future investigation should adopt a broader view, not only considering the effect of acute fluctuations, but also considering the "permissive" effect of the daily hormonal milieu, which I argue is more likely relevant to skeletal muscle adaptation.

Limitations

There are limitations to the present work that are outlined below and should be acknowledged when interpreting the results shown in this thesis.

Studies 1 and 2

Although the elite status of coaches can be perceived as a strength of these studies, it may also serve as a constraint. The uniformity in coaches' status invites circumspection in the interpretation and application of results across the broader spectrum of rugby practitioners. The perspectives articulated may not align with those espoused by sub-elite coaches, those working with amateur athletic populations, or those in other sporting disciplines. Occupying a senior role within an elite team should not be considered an automatic reflection of high competency and knowledge levels. Furthermore, the majority (three-quarters) of the coaches interviewed were male. While this mirrors the current international landscape, it might be perceived as introducing a potential bias in light of the subject matter under investigation.

Study 3

While this study encapsulated a broad geographical spectrum, a recognised limitation is the absence of ethnographic data among the respondents. The potential influence of ethnicity on physiological responses and perceived symptoms among HC and non-HC users remains to be investigated. Another constraint of this study lies in the lack of specificity related to OCP use, that is, the omission of data regarding the type of OCP, brand name, and progestins utilised. Future investigations should account for the impact of HC usage duration on health, training, and performance parameters, especially considering that 28.2% of HC users in this study had been continual users for five years or more. The long-term implications of such extended use are yet to be understood, an issue of significant relevance given that one-third of the respondents in this study do not adhere to common practice guidelines for HC use, particularly the observation of a monthly "pill-free" period.

Study 4

The limitations noted below are not isolated to this study but are indicative of the broader research area. The present study harnesses data from a single team, potentially circumscribing its applicability to other elite teams, given the intricate and contextual nuances of match demands (Dalton-Barron *et al.*, 2020). The heterogeneity of methodologies across studies, particularly in terms of inclusion/exclusion criteria and velocity threshold application, imposes hurdles for direct comparisons. Discrepancies stemming from a lack of consensus on velocity thresholds may be magnified in female team sports where research is comparatively lacking (Sweeting *et al.*, 2017). Although the data reported herein outline the physical match demands, they fail to incorporate the influence of varying tactical strategies adopted by the team and/or their adversaries. Consequently, these data should be construed with an understanding of pertinent contextual factors, such as weather conditions, opponent calibre, playing style, and match significance. The present study did not collect ball-in-play data, which could have substantially affected the relative intensity and collision frequency (Pollard *et al.*, 2018). Practitioners should thus remain aware of the potential contextual elements when interpreting the data presented in this study.

Study 5

Firstly, the predominant proportion of the study participants were untrained, thereby imposing constraints on extrapolations to athletic or highly trained demographics. The examined studies did not disclose specifics pertaining to participants' occupation or routine physical activity levels, which could potentially introduce confounding variables to their outcomes. Furthermore, the strength models only incorporated specific compound exercises. The inclusion of studies featuring single-joint outcome measures (for instance, elbow flexion or knee extension) could augment the quantity of effects and compound the complexity of the models, potentially leading to disparate results.

Study 6

The included studies investigating the influence of HCs on resistance exercise training adaptations focused solely on OCPs. It is incumbent upon future research to extend this scope to incorporate various forms of HCs, each of which engender distinct hormonal profiles, and their potential resultant impact on resistance exercise training adaptations. As for future studies specifically delving into the influence of OCPs, an elevated level of detail is mandated, such as outlining the particular type of OCP used. Future studies should also take pains to design intervention groups meticulously to mitigate the amalgamation of OCP users who use varying OCP types and dosages or to account for these subgroup variations appropriately in their statistical analysis. The potential impacts of HCs and OCPs on power-related adaptations remain underexplored and require further investigation.

Emerging Issues and Future Directions for Research in Physical Preparation for Female Athletes and Women's Rugby Union

Since beginning this PhD, women's rugby union has undergone a time of significant change. The sport is increasing in its professionalism with many more international squads contracting players (*Contracts for 30 Scotland Women rugby players and two new semi-pro teams as part of four-year plan to grow the game*, 2022; *Italy reward 25 players with central contracts*, 2022; *Wales Women award 17 further contracts as Cunningham extends stay*, 2022; *'Irish Rugby | McDarby Appointed Head Of Women's Performance & Pathways', 2022*). Future research should capitalise on this time of change and aim to measure the impact of professionalisation of the sport on anthropometric and physical performance characteristics, while also monitoring injury prevalence. Although it is largely anecdotal, there is a perception that professionalisation of the sport will confer rapid increases in physical performance, and researchers should aim to quantify this effect which may aid in informing policy in other female sports which are largely amateur in nature.

Moreover, an argument could be put forth advocating for both practitioners and researchers to distance themselves from an androcentric perspective on physical preparation in women's rugby union. In other words, women's rugby union should be recognized as a distinct sport, warranting a 'first principles' approach. It prompts the question, should our goal be to facilitate the emulation of the men's game by female players, or should we regard women's rugby union as fundamentally unique, framing our research enquiries around a profound understanding and appreciation of the sport's characteristics?

Although additional research investigating the potential influence of the menstrual cycle and hormonal contraceptives on acute performance and chronic adaptations to resistance exercise training is warranted, the orientation of the research questions should seek to generate consequential findings with the capacity to impact the practices of strength and conditioning coaches, as discussed previously. Although beyond the scope of this dissertation, female-specific physical preparation considerations related to pregnancy and subsequent postnatal return-to-play protocols also merit further examination.

A common theme highlighted throughout the chapters of this thesis is the limitations of the current body of research relating to the factors relevant to the physical preparation of women’s rugby union players. One of the most commonly cited limitations is the lack of specific research on women’s rugby union and small sample sizes. To improve both the quantity and quality of research in women’s rugby union we must begin to foster collaborative agreements between rugby unions and academic institutions, allowing for the development of appropriately powered multi-site, international research projects.

Concluding Remarks

In conclusion, further research on women's rugby union is required to better inform practitioners striving to adopt an evidence-based approach. Fundamental research relating to physical, performance, and match-demand characteristics is lacking, and this thesis has contributed valuable data to reduce this knowledge gap. Although the menstrual cycle and hormonal contraceptives may theoretically influence acute performance and adaptations to resistance exercise training, this is a complex and highly nuanced area which requires further investigation. Coaches should again adopt a pragmatic approach, appreciating the high level of variability observed between- and within-individuals.

While much research remains to be done in this area, women's rugby union continues to grow and evolve into an increasingly professional sport, with research interest increasing accordingly. As a researcher, I look forward to continuing to play a small role in producing meaningful research which may directly influence practitioners at the forefront of women's sports.

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Appendices

Appendix A: Published article in the International Journal of Sports Science and Coaching

Original research article

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'*There's a perfect way to do things, and there's a real way to do things*': Attitudes, beliefs and practices of strength and conditioning coaches in elite international women's rugby union

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Abstract

Optimal physical performance is a product of specific and tailored training. There are well-established sex differences in anatomical, physiological, and performance factors between biological males and females, which may have implications for physical preparation. A potential knowledge gap exists in relation to sex-specific differences in physical preparation because practitioners largely rely upon empirical evidence collected in male subjects for reference when devising interventions for female athletes. Therefore, this study explored the attitudes, beliefs and practices of strength and conditioning coaches ($n = 8$; M/F, 6/2) in elite level (international) women's rugby union using semi-structured interviews (mean ± standard deviation duration 59 ± 15 minutes). The interviews explored differences in coaching elite female rugby players compared to males, with specific focus on training methodologies and understanding of pertinent aspects of female physiology. Reflexive thematic analysis was utilised to generate a rich qualitative dataset. Analysis resulted in the identification of higher-order themes: *developmental stage of women's rugby, physical preparation, and education.* Additional subthemes were created to facilitate organisation and presentation of data. The majority of coaches consider sex-specificity when devising physical preparation interventions as a function of training experience, rather than physiological between-sex differences, yet there were conflicting, and often erroneous understanding of female-specific considerations. To the authors knowledge, this is the first study to investigate attitudes, beliefs, and practices in elite level strength and conditioning coaches regarding sex-specific differences, and as such, illustrates the current understanding and opinions of practitioners in international level women's rugby union.

Keywords

Hormonal contraception, injury risk, menstrual cycle, physical preparation, professionalism, resistance training, sex differences

Introduction

Women's rugby union is one of the fastest growing demographics within rugby union, experiencing significant increases in participation numbers in recent years.[1] Despite the large growth observed in women's rugby and the professionalisation of the men's game almost three decades ago, the majority of 'elite' female rugby union players, that is internationals, participate as amateurs.[2] Total and relative running demands, that is distance covered and velocities achieved, differ between the men's and women's game.[3] Collision frequency has been reported as similar[3] or higher in the women's game.[4] Women's rugby union has also been observed to adopt more possession-driven attacking tactics compared to increased kicking frequency in the male game, resulting in a more open and continuous style of play.[5] These factors may warrant differing approaches to physical preparation between the male and female athletes in their respective codes.

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Appropriate physical preparation and training is an integral element of long-term athletic development.[6,7] There are well-established between-sex differences in anatomical, physiological and performance factors,[8,9] which may have implications for physical preparation. Females also display differing hormonal profiles compared to males at rest and in response to exercise, which may also potentially influence performance.[10–12]

The cyclic fluctuations of endogenous sex hormones, namely oestrogen and progesterone, experienced by eumenorrheic females may theoretically influence acute performance and chronic adaptations to exercise training, yet the evidence for this is equivocal at present due to the lack of a sufficient number of high quality studies.[13,14] Hormonal contraceptives alter the endogenous hormonal profile of females and this may also influence adaptive responses to exercise training,[15–18] but the influence has not yet been fully elucidated again due to the paucity of high quality studies.[19] Qualitative and self-reported data suggest that a high prevalence of female athletes experience negative side-effects of the menstrual cycle (∼80%) and hormonal contraceptive use (∼24–40%), which may negatively influence performance in acute contexts.[20–22] Lastly, between-sex differences in muscle fatigability[23] and injury rate profiles[24] have been observed.

These observations suggest a possible need for sex-specific physical preparation, but whether these between-sex differences do indeed necessitate differing methodological approaches to optimal physical preparation is yet to be fully explored. In response to matched resistance exercise training interventions, males and females respond similarly in terms of strength and hypertrophy outcomes,[25] but this response is largely observed from untrained and recreationally-active individuals, which limits the inferences for athletic populations.

Given the general lack of evidence-based guidelines in the domain of sex-specific requirements for physical preparation, the present study explored the attitudes, beliefs and practices of strength and conditioning coaches in elite level (international) women's rugby union, with specific focus on training methodologies and understanding of pertinent aspects of female physiology. Exploration of between-sex differences, if any, in their approach to the preparation of female athletes will enable the identification of unique challenges faced by elite level practitioners, while also identifying any pitfalls or gaps in their current knowledge, which will inform both research and practice in the future.

Research philosophy, design, and methods

Research philosophy and study design

As pracademics (practitioner-academics) concerned with the generation of practically-meaningful insight, this study was underpinned by a pragmatic research philosophy.[26] Pragmatists adopt a practical approach to investigation, rejecting both pure positivism (i.e. the existence of a single reality and universal truths that can be objectively measured) and pure constructivism (i.e. reality is constructed by individuals and groups with no research finding more 'correct' than another), while not committing to any specific ontological or epistemological view. The present study addressed a relevant applied issue and did not assume an unbiased interaction between authors and data. Rather, the lived experiences of the authors were acknowledged, and the authors were considered co-constructors of knowledge, aided by their own experience leading, assisting and performing in elite sport.

Participants

Following ethical approval from Dublin City University Research Ethics Committee (permit number: DCUREC2020/283), eight strength and conditioning coaches in elite level (international) women's rugby union were recruited utilising a purposive, criterion sampling approach.[27] Invitations were extended to the thirteen highest ranked international women's rugby union teams as per world rugby rankings on March 1st, 2021[28] via email to the respective rugby unions. Inclusion criteria stated that the participants had to be the current 'lead' strength and conditioning or athletic development coach for a senior international women's rugby union team, or have held that position within the previous 12 months. Participants' characteristics have been summarised in Table 1, which has been presented to ensure anonymity of participants is maintained.

Procedures

Semi-structured interviews were utilised to allow for rich exploration of the key research questions, while also permitting flexibility to follow alternate lines of inquiry that emerged during the interviews. This process has been previously utilised to obtain qualitative data for the experiences of strength and conditioning coaches.[29] Prior to data gathering, a semi-structured interview guide was developed and informed by relevant literature and refined using pilot testing. Pilot interviews were conducted on two separate coaches (1 male, 1 female), which resulted in alterations to the interview guide to ensure alignment of questioning with study aims and objectives. These alterations consisted of modification of question structure and addition of probes to the interview guide. The interview guide consisted of introductory, central and closing questions, utilising a pliant approach to encourage meaningful discourse and ensure rich exploration of participant experiences. The interview guide addressed two distinct research questions; (i) Do coaches use differing physical preparation strategies between sexes, and what influences these differences, if any, and (ii) Do coaches have differing interpersonal interactions between male and female athletes? Due

Table 1. Descriptive characteristics of participants.

Sex	$n = 8$ (6 male, 2 female)
Age	35.7 ± 5.4 years (range, 31–46 years)
Location	6 Northern Hemisphere, 2 Southern Hemisphere
Education level	Bachelor's degree, $n = 3$
	Master's degree, $n = 5$
Number of years coaching	13.3 ± 4.7 years (range, 7–21 years)
Number of years coaching at international rugby level	6.5 ± 6.3 years (range, <1–16 years)
Current or former rugby player	Yes, $n = 7$
	No, $n = 1$
Number of teams previously coached	11.6 ± 7.7 (range, 4–25)
Number of female teams previously coached	4.8 ± 4.9 (range, 1–14)
Coached in sport other than rugby?	Yes, $n = 7$
	No, $n = 1$
Coached youth athletes?	Yes, $n = 7$
	No, $n = 1$

Data reported as mean ± SD where appropriate.

to the significant quantity of data gathered from these interviews, the themes relating to interpersonal interactions will be the subject of a separate report in order to enable appropriate depth of discussion for both research questions.

Detail-orientated probes were used to enhance the insights provided by the participants.[30] For example, these included '*Can you explain exactly how you implemented that*?' or '*Why did you do that?*'. Clarification probes were used to further explore points that were unclear or vague.[31] These included using phrases such as '*Just to be clear, can I confirm that when you say X you mean…?*'. All interviews were conducted online via *Zoom* (Zoom, San Jose) by the lead author, with due consideration given to the methodological and epistemological issues that conducting interviews in this format presents.[32] Audio recordings were transcribed verbatim using *Happyscribe* transcription software (Happy Scribe, Dublin) and the transcripts were manually checked for accuracy by the lead author. Following transcription, all data were anonymised with a participant identification number assigned for the purpose of reporting. Interviews were conducted during the period April to October 2021 and lasted between 28:44 and 84:16 minutes (63:14 ± 17:59 minutes: seconds), resulting in 145 pages (72,294 words) of data (18.1 ± 4.3 pages per interview).

Data analysis

Data were analysed using reflexive thematic analysis utilising the framework provided by Braun and Clarke[33] to ensure appropriate application of thematic analysis. Thematic analysis is used to identify, organise, analyse and report qualitative data sets into concise patterns, offering insights into lived experiences,[34] and has been previously used to garner insights into experiences of strength and conditioning coaches.[35,36]

The first stage of analysis involved ensuring of accuracy of transcripts and immersion in the overall dataset, consisting of repeated listening to recordings and reading of transcripts, leading to the generation of 'points of interest' and potential codes and themes. Transcribed data were imported to NVivo Pro (QSR International, Doncaster) NVivo was used for the purpose of storing and organising the dataset, enabling the research process rather than being a key feature of the analysis per se. The NVivo software was not used to lead the analysis process, and consistent reading and re-reading of the original transcripts ensured the lead author did not become distant from the data or participants.[37] All data were again thoroughly examined, and codes assigned to lines and/or paragraphs relevant to the central research questions. All codes were then organised into themes and subthemes (as nodes). Reflexive thematic analysis was utilised to analyse the data and refine themes and subthemes. Following reflexive thematic analysis, and reflecting the sixth phase of the data analysis process, a consensus was agreed upon by the research team and a report of main findings was produced. This phase was recursive and given the reflexive nature of the process woven into the entire process of data analysis.

Trustworthiness

The application of thematic analysis in sport and exercises sciences has been previously criticised,[38] so it is imperative that best practices are observed to ensure high quality data are reported. Verification meetings of the research team resulted in the alteration, merging, and deletion of themes and subthemes. Verification methods are recommended to improve trustworthiness of data.[39] Authors listed at positions two (PH) and three (AMN) of the research team acted as 'critical friends' to the lead author and discussed similarities and differences in interpretation of the data, challenging the lead author until a consensus was agreed, with author four (BE) acting as a moderator where needed, leading to further refinement of themes and subthemes.

Reflexivity and positionality

The lead author utilised reflexivity throughout the research process which is described as 'an act of self-reflection' that considers how one's own opinions, values and actions shape how data is generated, analysed and interpreted.[34,40] The following information provides context which may be used to assess credibility of this research and improve its transparency.

The primary research question was devised as part of a wider investigation by this research group into sex-related differences in athletic preparation. This area of applied research is largely understudied, particularly in the context of rugby union. The lead author has practical experience and interest in female-specific strength training, and understands the pertinent issues faced by practitioners in this domain. During the development of the interview guide, subsequent data collection and analysis, the lead author aimed to separate his own experience and beliefs from those held by the participants and to remain objective. The experience of the lead author allowed for a credibility with participants and facilitated the detection of lines of enquiry during the interview process that may otherwise be overlooked by an interviewer of differing background.

The positionality of the lead author may be viewed as a strength of this study. Positionality is aligned with reflexivity and understands that research is a process in which our own experiences shape and, dialectically, is shaped by the ongoing research process and its importance is increasingly recognised in research.[41] The background of the lead author offered him 'insider' status when speaking with participants and this is arguably invaluable to the conduct of the study.[42,43] The participants recruited may be viewed as an unknown group, who are regarded as hard to reach. This status offered subcultural legitimacy and allowed for initial access as well as the development of trusting relationships between interviewer and interviewees.

Results and discussion

The aim of this study was to explore attitudes, beliefs and practices of strength and conditioning coaches in elite level (international) women's rugby union. The thematic analysis produced three higher-order themes under the central organising theme of "Differing Coaching Approaches to Male and Female Athletes" (Figure 1). These higher-order themes and subthemes are presented in detail with anonymised quotes included to support discussion points and explicate the participants' experiences. Additional words are placed in parentheses to clarify intended meaning or provide further context where relevant. Punctuation was added to quotations to reduce ambiguity where required. Additional representative quotes for each subtheme are provided as Supplementary Information.

Developmental stage of women's rugby

Women's rugby is arguably in its infancy compared to the men's game (which turned professional in 1995), and is currently experiencing rapid growth in participation levels.[42] Although some nations have professionally contracted players, the majority of elite level female rugby players partake under amateur status. The data generated four distinct subthemes concerning the development stage of women's rugby; definition of elite, evolving nature of gameplay, professionalism, and training age.

Definition of elite. Overall, it was expressed that while the international arena represents the 'elite' of their sport, this definition holds differing connotations for males and females.

> *So, elite in a male is very different to elite in a female in my world at the moment... this is an elite female team, but it's an elite female team that's amateur that's only training twice a week.* (Coach 2)

The coaches also reported females can rise to international level much quicker, with different training and developmental pathways compared to males:

> *Whereas I found with senior females, just because they've probably got to that level without having had the years of experience in the gym or that big training age in resistance training.* (Coach 2)

> *You might get a girl who's playing at the top level who physically has no training age at all.* (Coach 6)

The term 'elite' in a sporting context has been argued to often be applied erroneously, both across and within sports, and athletes should not be automatically be enthroned with elite status by merit of competing at an international level.[45] A more appropriate method of determining the status of an athlete should utilise objective markers of performance where possible compared to normative values, such as personal bests and physical performance characteristics.[46] However, this approach does not consider that elite athletes possess more than just higher than average physical attributes, with high levels of domain-specific skill execution also being imperative to performance. Physical testing batteries do not account for this. Taxonomies for classifying the status of athletes in sports science research have been posited for both physical[47] and skill-related attributes,[48] which may aid practitioners in conceptualising the current position their athletes reside upon the novice-elite spectrum, akin to employing a participant classification framework.[49]

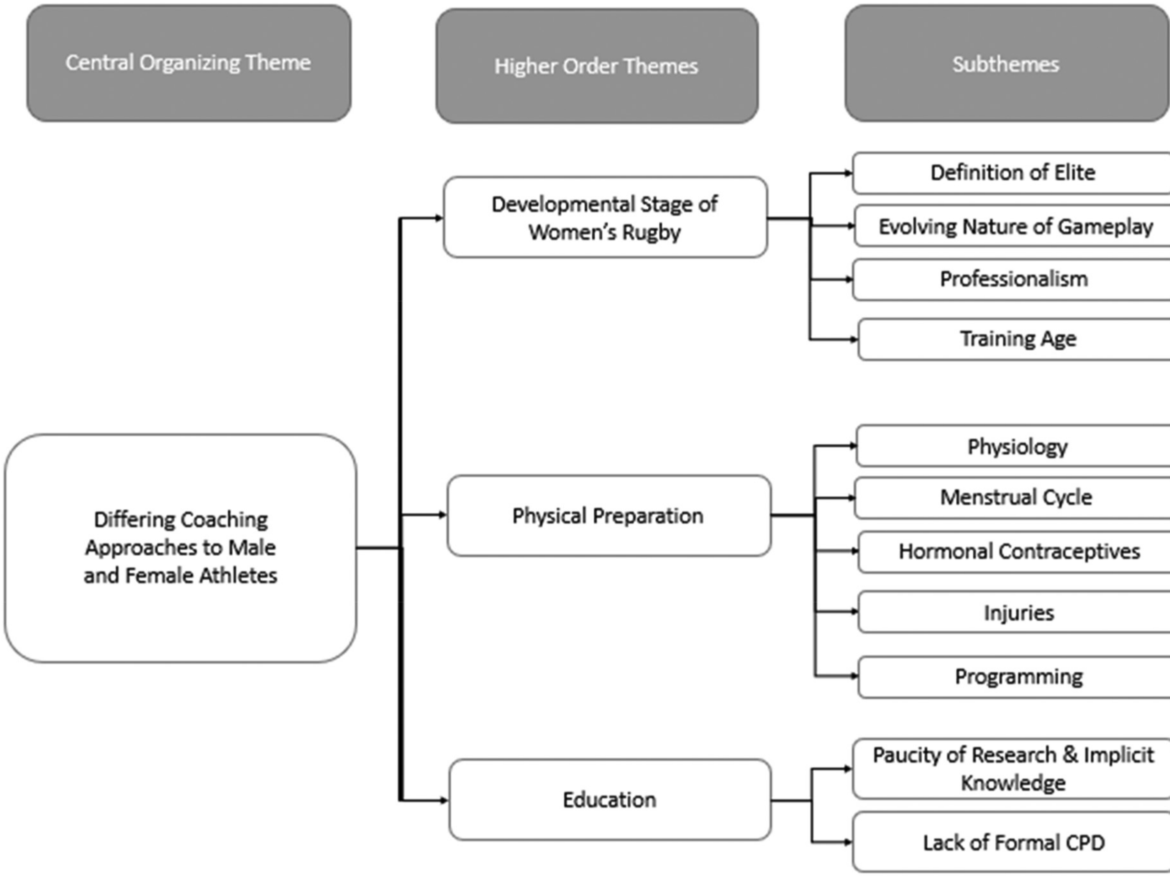

Figure 1. Schematic representation of central organising, higher order, and subthemes.

Evolving nature of gameplay. Four of the coaches (Coach 2, 3, 5, and 6) acknowledged the differing nature of gameplay between the sexes as a key difference which influenced their practices. The ongoing evolution of women's rugby was considered a key issue in the development of future physical preparation strategies.

> *We've seen from 2014 to 2017 as there is only a three-year gap to [Women's Rugby] World Cups, the game had changed dramatically and I would hazard a guess in 2022, we're going to see that change again. We're going to see a more evolved, more conditioned [female] athlete that will have a higher tolerance to training and just be more conditioned and stronger.* (Coach 5)

There is a dearth of literature investigating the game demands of women's international rugby union. Because no study to date has directly compared international men's and women's teams using matched methodology, any interpretation of these data for between-sex differences is limited. Yet in other sports such as soccer where the women's game is more established, a divergence exists in which the men's game has higher running demands and intensities than their female counterparts.[48,49] From the available evidence in rugby union, this divergence in the game demands between the men's and women's game also seems apparent, with the men's game having higher intensity running demands, with 'worst case scenario' total distances of approximately 154−184 m/min in men's international rugby compared to approximately 143−161 m/min in the women's game.[52,53] The opinion that the women's game has intensified in recent years is also supported by empirical evidence showing an increase in sprinting and overall running demands in a five-year longitudinal study encompassing 2015−2019.[3,54] Total average distance covered in a game ranged from 2410 m (front row) to 4605 m (outside back) in 2015 compared to 3240 m and 5283 m for front rows and outside backs, respectively in 2019.[3,54]

The growth of women's rugby was suggested to have led to changing physical characteristics of players and increased heterogeneity of physiques.

> *You had quite a homogeneous body shape in women's rugby… Now, I think there's more girls playing rugby, which means you get more, you know, different shapes coming through, more suited. Plus the roles are more specialised. You know, the teams will go after teams at scrum*

> *time now. So, you know, you've got a big, particularly powerful pack where historically it would be like very homogenous body shape.* (Coach 6)

Anthropometric profiles of international women's rugby players have significantly changed in recent years with athletes displaying lower levels of body fat, and greater levels of muscle mass.[54] Participation numbers in women's rugby are increasing year on year, so one would anticipate further diversification of anthropometric profiles with further increasing of muscle mass, which has been observed in other sports.[55]

Professionalism. The paucity of professionalism in women's rugby was identified as a major confounding variable that influenced and constrained the practices of the coaches.

> *But even if we were to look at the Six Nations and gather whatever data you want and you get an average of that. How true is that average when you've got a professional team, a semi-professional team and four amateurs?* (Coach 2)

As previously noted, female rugby players are sometimes viewed as "not truly elite" compared to their male counterparts. The confounding variable of professionalism must be acknowledged in this respect. If coaches aim to strive towards parity between the relative athletic abilities of male and female athletes, this parity may not be achieved under amateur conditions where factors such as training opportunities, facilities, and multidisciplinary support teams are not equivalent to professional status. Reported differences in coaching practice undertaken with male and female rugby players could be argued to not be due to biological sex of the respective athletes and the associated differences in anatomy and physiology, but rather is a result of constraints and extraneous factors resultant from the absence of professionalism and resources for the women's game.

Five coaches (Coach 2, 3, 4, 7, and 8) viewed the lack of professional status and decentralisation of players as a significant barrier in their practice.

> *We're getting girls once a weekend every three weeks. There was only so much we can really tweak because I say back to it was a camp weekend, and it was probably just a state of where we were at really as well. So I wouldn't say it gold standard practice. And that's probably something that gets overlooked a little bit as well. You can't do everything when you see them once a month.* (Coach 8)

All coaches expressed the opinion that female rugby players generally have lower level of gym-based motor skill competence compared to their male counterparts, with Coach 8 stating '*Some of our six nations camps were spent teaching some girls to lift… Some girls needed to come in and learn how to push, pull and squat*'. The coaches' opinion was also that, in general, male athletes are exposed to structured gym-based training earlier in their sporting careers through school- and academy-based programmes in adolescence, while female athletes generally do not get exposed to structured gym-based exercise until much later in their development, often not until adulthood.

Five coaches (Coach 3, 5, 6, 7, and 8) expressed views that female players have less training and athletic development opportunities available to them compared to their male counterparts due to differing structures and professionalism of the codes.

> *The problem is I was getting some girls coming to me for [Country] International set up at 24/25 [years old], maybe even older, who had very little support or even the support they were getting at their clubs wasn't of a standard most 15 year old lads would have been getting just because of the support and the funding behind it.* (Coach 8)

This lack of exposure may lead to weaknesses in fundamental athletic motor skill competencies that presents a barrier to long-term athletic development and success.[6,7,56] Sex-based inequalities in sporting support structures has been posed as a significant barrier to both grassroot participation levels and progression of elite performers.[57] Improved support structures, aligned to those offered to male players may enhance the athletic abilities of female players, theoretically resulting in improved performances, self-efficacy and player retention.

Training age. While all coaches stated they do not differ their programming significantly due to sex-differences, it was universally acknowledged that any differences in their approach to physical preparation were generally due to a younger training age compared to males.

> *It's a massive difference [between males and females] in the sense of training age because they're not exposed to the level of training that you would need them to be.* (Coach 3)

Notably, the coaches expressed the opinion that the majority of 'elite' female rugby players have a very low training age pertaining to specific aspects of athletic development (i.e. gym-based training) when entering the international set-up. This suggests that female rugby players are under-developed with respect to currently adopted long-term athlete development models, which advocate for structured strength and conditioning training during adolescence.[6]

Lower technical ability due to lack of training age was expressed by six coaches (Coach 2, 3, 5, 6, 7, and 8) as a significant influence on their approach to physical preparation.

> *They [have] got a very poor level, technically, especially in the gym, the level needed to be increased a lot to work safely also to perform and it's a real problem for us.* (Coach 7)

> *The technical and tactical characteristics and the physical characteristics are not quite as well emerged. You might get a girl who's playing at the top level who physically has no training age at all*'. (Coach 8)

These reported opinions again highlight the opinion that female athletes appear to not achieve sufficient stimulus from both their school-based physical education and club-based training to develop a high level of technical ability in the respective aspects of the athletic motor skills competency framework.[56]

Physical preparation

Females may require a different approach to physical preparation due to anatomical and physiological differences compared to males.[54] Female athletes display differing injury risk profiles,[59,60] and factors such as endocrinological differences due to the menstrual cycle and hormonal contraceptives may lead to augmented adaptive responses to training, presenting unique challenges and requirements when designing and implementing a physical preparation programme.[14,61] Five subthemes are presented regarding physical preparation: physiology, menstrual cycle, hormonal contraceptives, injuries, and programming.

Physiology. Five coaches (Coach 3, 4, 5, 6, and 8) expressed the opinion that unique aspects of female physiology may lead to differences in adaptive responses to exercise training, and therefore influence the coaches' practices.

> *I guess if you look at physiology because of hormonal cycles, because of the nature of the muscle and everything else. Yes, women are going to respond differently…There may be some modalities of training that are more beneficial than others.* (Coach 5).

The opinions highlighted potential inaccuracies in the coaches' understanding of contemporary knowledge in female physiology as it pertains to neuromuscular adaptations to exercise training. Although it is theoretically possible that males and females respond differently to resistance exercise training due to divergent hormonal profiles, this is not yet supported by strong empirical evidence to date. When standardised for quantity of muscle mass at baseline before intervention, males and females do not display divergent outcomes for lower-body strength and hypertrophy in response to matched resistance exercise training interventions.[25] Augmenting programming based upon assumptions of divergent adaptive responses due to between-sex differences in anatomy and physiology is not presently evidence-based. Decisions regarding physical preparation should, therefore, be based on better established factors such as training status (age).

Menstrual cycle. The necessity to acknowledge the potential influence of the menstrual cycle was expressed by all coaches, with for example, Coach 5 stating; '*Your gut says it does [menstrual cycle impact performance], your athlete's gut says it does when you talk to them. They know their bodies themselves*', yet four coaches (Coach 1, 3, 5, and 8) noted that they do not actively monitor the phases of the menstrual cycle with their athletes.

> *It's hard to attribute anything to the menstrual cycle because I don't know what their menstrual cycles are.* (Coach 1)

Despite calls advocating for raised awareness and monitoring of menstrual dysfunction in athletes,[62] half of the coaches interviewed do not actively monitor menstrual function with their athletes. Monitoring of menstrual cycle status is a relatively cheap and efficient process that can identify individuals at risk of relative energy deficiency in sport (RED-S) and menstrual dysfunction, a pertinent risk factor for adverse health and performance outcomes in female athletes.[63] With the increasing availability of cost-free menstrual cycle tracking applications, menstrual cycle monitoring can arguably be seamlessly adopted in a performance environment.

While all coaches expressed the opinion that the menstrual cycle may impact performance, they varied in their views when describing the mechanism by which they believe this effect occurs, with Coach 2 stating '*I definitely have some girls…when they're in the follicular phase, they're absolutely smashing it…when they're coming close to their menstrual cycle [sic] they don't feel as hot, they do take longer to recover… Half the time I don't know if it's a self-fulfilling prophecy of the fact that I've warned them on it [potential impact of menstrual cycle]*'.

Again, these responses illustrate a potential lack of understanding of the current evidence regarding menstrual cycle phase and exercise performance. An apparent paradox is evident in the existing literature, wherein a consistent trend of qualitative and self-report data reports that female athletes experience a high prevalence of symptomology relating to the menstrual cycle and perceive it to negatively impact sporting performance,[64,65] yet when examined objectively, menstrual cycle phase does not consistently affect acute performance indicators.[13] However, it must be noted that the majority of research conducted to date in this domain is of low quality, with small sample sizes and clear methodological flaws (i.e. lack of appropriate controls, and lack of blood sample confirmation of hormonal status) and thus limits firm conclusions.

All coaches reported that they have adjusted planned training or implemented coping strategies with an athlete due to menstrual cycle symptomology, but noted this is done on an individual basis reactively rather than proactively.

> *We'll just drop a little bit in terms of what you're doing weights wise, or we'll change the training session to allow you to complete it a bit more effectively, or we'd apply a bit more choice around what they're doing in certain elements of training… or we'd take away an appearance or something like that and allow them to sleep or do things like that.* (Coach 6).

Based on current empirical evidence and best practice guidelines, adopting an individual approach to the development of menstrual cycle-related coping strategies is advisable.[12] There is large inter- and intra-individual variability observed in menstrual cycle-related symptomatology,[20,65] therefore an individual, auto-regulated approach to symptom management is arguably superior to a generalised proactive strategy. A desire to implement so-called "phase-based training" was only expressed by Coach 1 who stated '*I would love to do more phased based programming around each individual to maximize their maximize that training around the cycle… looking for ways to take advantage of the menstrual cycle and make it an ergogenic aid*'.

As previously noted, there are currently no evidence-based guidelines or methods to prescribe training based on a specific phase of menstrual cycle. This coach displayed a belief that phase-based training would enable the coach to 'take advantage' of the menstrual cycle. Although this sentiment has a potential theoretical basis,[14] the empirical evidence for superior outcomes adopting such an approach is currently scant. Regardless, the reasons expressed for not using phase-based training were predominantly based upon logistical feasibility, with four coaches (Coach 2, 6, 7, and 8) believing that phase-based training to be unfeasible and impractical to implement in a team sport performance environment

> *There's a perfect way to do things and there's a real way to do things…we can't change the playing and training schedule based on someone's cycle because you've got 40 girls, you've got 40 different cycles going on. You've got 40 different degrees of symptoms, you've got people on contraception, et cetera, things like that.* (Coach 8)

Hormonal contraceptives. Two coaches (Coach 1 and 8) stated that hormonal contraceptive use may influence performance, but were ambivalent in their opinions, with Coach 1 stating '*Whether or not they're on contraceptives also like throws in a whole other mix*', whereas Coach 8 stated '*From a theory standpoint, I'd say yes [hormonal contraceptive impact on performance], but I never got a chance to actually practically apply it and see*'.

Hormonal contraceptive use does not appear to acutely affect athletic performance,[19] yet the majority of literature to date is again of low quality, with small sample sizes, lack of standardisation and inadequate familiarisation, among important issues that limit interpretation. There is equivocal evidence regarding the influence of hormonal contraceptive use on adaptive responses to resistance exercise training with the currently limited evidence base showing positive (molecular markers),[16] negative (hypertrophy, strength, inflammation)[17,18,66] and neutral (hypertrophy, strength, power)[15,57,67–71] outcomes relating to hormonal contraceptive users compared to non-users. Coaches should be aware that there are currently no evidence-based recommendations relating to adapting training approaches based on hormonal contraceptive use.

Six coaches (Coach 2, 3, 4, 5, 6, and 7) stated that they have never considered the potential effects of hormonal contraceptives on performance.

> *I've got to hand up and say that is one of my blind spots [hormonal contraceptives].* (Coach 5)

> *I have no idea [regarding hormonal contraceptives].* (Coach 7)

Three coaches (Coach 1, 4, and 8) expressed opinions on potential health concerns relating to hormonal contraceptive use, with Coach 1 stating '*from my understanding, from what I've read thus far is that using oral contraceptives create more harm than good*'.

Given the high prevalence of hormonal contraceptive use in athletic populations and their sometimes associated negative side-effects,[20–22,72,73] coaches or medical staff should monitor the prevalence of hormonal contraceptive use by their athletes and be cognisant of the potential influence of support staff, while also being aware of emerging evidence and best practice guidelines pertaining to hormonal contraceptive use within sport. The motivation for hormonal contraceptive use is personal and multi-faceted, and this must be considered when discussing hormonal contraceptive use with athletes.[72]

Injuries. Six coaches (Coach 1, 2, 4, 6, 7, and 8) expressed the opinion that anatomical differences influence injury risk, with Coach 2 stating '*The only difference [between males and females] is really that I have is, you know,* *there are certain parts of the female body, I think, that are more susceptible to injuries*', while Coach 6 specifically highlighted the quadriceps angle (Q-angle) as a significant risk factor, stating that '*The large Q-angle and the wider pelvis in tall female athletes does represent a genuine ACL [anterior cruciate ligament] risk*'.

The opinion expressed that females display differing injury profiles and are at higher risk of knee injuries, specifically anterior cruciate ligament injuries, is supported by the literature.[24] However, the attribution of increase knee injury risk to Q-angle by several coaches displays a potential lack of understanding of current evidence related to female sports injury risk. When standardised for baseline height, males and females display similar Q-angles[74] and static measures of Q-angle have questionable clinical significance.[75]

Programming. Overall, the coaches interviewed in the present study do not approach physical preparation differently for female athletes compared to males.

> *I wouldn't do anything different. Again, it's just more your expectations are different…we can still do the same program and still do the same running.* (Coach 3)

Based on the current, albeit limited evidence base, there is not yet a strong rationale for sex-specific differences in programming. Females respond similarly to males in strength and hypertrophy adaptions following matched resistance training protocols.[25] A sexual dimorphism does appear to exist in acute fatigability during high intensity performance bouts, yet this has largely been observed in isometric based tasks rather than isotonic contractions.[23] Although this sexual dimorphism is observed in acute fatigue during isometric contractions, the same divergence is not observed in recoverability of neuromuscular function following dynamic and eccentric focused resistance exercise training sessions.[76–78] Considering this, it would be ill-advised to train females differently to males based primarily on potential differences in fatiguability.

Regarding exercise selection, there is no strong evidence-based rationale for differing exercise selection for female athletes, and unsurprisingly all coaches stated that their exercise selections do not differ between players due to sex, with, for example, Coach 4 stating '*there's no difference in that [exercise selection]*'.

Given the increased risk of anterior cruciate injury present in females,[58] it may be prudent to ensure female athletes are following an appropriate neuromuscular training programmes, incorporating lower body strengthening exercises with a specific focus landing stabilisation, which has been consistently shown to reduce anterior cruciate injury risk in female athletes.[79] However, the same advice would be pertinent for male athletes also.

Education

Given that sports science and elite sport is such a dynamic and evolving domain, it is imperative to understand what resources and strategies practitioners employ to ensure appropriate continued professional development (CPD). Two subthemes were identified, namely lack of formal CPD, and paucity of research and implicit knowledge.

Lack of formal CPD. Coaches noted there is a lack of formal educational programmes specifically regarding physical preparation of female athletes provided by their respective unions. Five coaches (Coach 1, 3, 4, 5, and 7) rely primarily on non-peer-review resources, with colleagues being used as the main source of education, as typified by Coach 5 stating '*In short, no [education provided by union]. It's been a reasonably steep learning curve, I would say, from some of our more qualified, more experienced male coaches*'. Coach 4 displayed aversion towards academic research, stating '*What you can't quantify, can't be published. And that's a huge issue. And where my issue with academia is, it is now how many papers can I publish versus what problems am I trying to solve?… there's not a lot of ground-breaking things have come out, so it's like I think it needs to go…I then go into talking to coaches and then watching presentations…[the presenter] provides like real life practical [information]. It doesn't matter about the study design. Hey, I did this, I did that. I don't care if it's statistically significant. My athletes got better. They improved on the field. I don't I don't need stats to tell me that*'.

The coaches displayed a clear desire to further understand the requirements of the female athlete, but most noted a clear lack of opportunity for CPD on this specific topic within their union. Social media and podcasts were viewed as a key resource for on-going professional development.

> *And then obviously in today's world, like social media and podcasts, and getting information out that way, I think right now that's kind of leading, leading the front on this topic anyways.* (Coach 1)

Although podcasts can be a valuable source of information, podcasts are unregulated non-peer-reviewed platforms and the accuracy of information disseminated cannot be ensured. However, the use of peer-reviewed literature as a source of CPD was being utilised by four coaches (Coach 2, 3, 7, and 8), with Coach 2 stating '*Google Scholar a lot [for CPD]*', and Coach 7 stating '*I'm often going on PubMed [for CPD]*'. The perceived lack of CPD offered, coupled with lack of utilising peer-reviewed sources suggests the respective unions engaging in formal educational opportunities, perhaps with innovative CPD offerings, for their practitioners would be advisable in this context.

Paucity of research and implicit knowledge. The majority of coaches in this study arguably present an androcentric view of beliefs and attitudes towards conditioning practices in women's rugby union. In other words, adopting practices from, and consistent with comparisons to, the men's game and male athletes. This perspective is most likely attributable to the viewpoint expressed by coaches relating to the lack of research in women's rugby. A prevailing opinion amongst the coaches was that a dearth of empirical evidence exists concerning the physical preparation of female rugby players, specifically concerning normative data regarding game demands and physical characteristics, with Coach 3 stating; '*There's not enough, evidence, or studies done on female sports*', and Coach 6 describing; '*Relative difference between positional characteristics is also something we don't understand*'. All of the coaches expressed the opinion that there is little available research on females that can inform practitioners. This viewpoint does not accurately reflect the body of evidence. While females are underrepresented in sports science research, they still account for approximately one-third of sports science participants,[80,81] but it must be noted that within studies relating to strength and hypertrophy outcomes or in highly-trained individuals, female representation is arguably lower. Research regarding best practices towards female athletes is constantly evolving and practitioners should be offered platforms to aid them in keeping up to date with, and correctly interpreting such information.

Study strengths and limitations

These coaches provided their insight and experience of sex-specific differences, albeit evidently few, in their approaches to physical preparation. The position held, and experience of the coaches is a clear strength of this study, although, of course, employment status is not necessarily a good indicator of expertise or knowledge. Nonetheless, to the authors' knowledge, this is the first study to investigate attitudes, beliefs, and practices in elite-level strength coaches regarding sex-specific differences, and as such, illustrates the current understanding and opinions of practitioners in international level women's rugby union. The qualitative methods employed in this study allowed for flexible analysis of rich information in a systematic and precise way.

Although the elite status of the coaches is considered as a strength of this study, it could also be viewed as a limitation. The homogeneity in status of the coaches should lead to caution of interpretation and application of results to practitioners in rugby as a whole. The viewpoints expressed may not be similar to those held by sub-elite coaches, or those working with amateur athletic populations or within other sports. The merit of occupying a senior position with an elite team should not be assumed *de facto* to reflect high levels of competency and knowledge. Also, three-quarters of coaches interviewed were male and while this is representative of the current landscape at the international level, it may be viewed as a potentially biased viewpoint given the topic under investigation.

Conclusions

This study provides important insights and contextual evidence to the understanding of sex-specific considerations in the physical preparation of female rugby players from the perspective of elite-level strength coaches, which to date has not been explored.

Women's rugby was reported by the coaches to be of a lower standard compared to the men's game in terms of 'elite' status and professionalism. Coaches highlighted that international female players often presented with low technical ability and training age in gym-based movements due to lack of systematic support within their performance environment and in developmental pathways. The improving standard of international women's rugby was acknowledged and with this in mind, coaches should be cognisant of current longitudinal trends suggesting increasing running demands and increasing heterogeneity of anthropometric characteristics. Women's rugby is currently experiencing significant growth and it is imperative that unions ensure appropriate support systems and infrastructures are available for their growing female demographic to capitalise on this rapid expansion.

Overall, while coaches expressed there are some female-specific considerations they are cognisant of regarding physical preparation, such as individual management of menstrual cycle symptoms, there was no meaningful difference in how they approached the physical preparation of females compared to males in terms of training methodologies. Differences in approaches to physical preparations are primarily driven by lower training age, and poorer technical ability of female athletes compared to males rather than distinct anatomical or physiological differences, a potential legacy of under-resourced developmental pathways, and support structures for female rugby players.

There were clear gaps in knowledge exhibited by the coaches regarding both the menstrual cycle and hormonal contraceptives. Coaches should be aware of the potential influences of the menstrual cycle and hormonal contraceptive use, and it would be advisable to implement appropriate monitoring systems pertaining to these aspects of female health and performance. Currently, there are no evidence-based guidelines which advocate for differing training methodology for female athletes, and it would be prudent for coaches to follow their current protocols but to be aware of the evolving research in this domain.

Coaches clearly strive to utilise an evidence-based approach where and when possible, but reported often lacking the necessary supports or information to do so.

Informal resources (i.e. social media and podcasts) and colleagues were identified as the primary sources of education that the coaches utilised. There was a perception amongst the coaches that empirical data in elite female athletes is practically non-existent. This misconception should be addressed in this population with the coaches also being encouraged to draw inferences from data in other elite female sports and populations, where appropriate. Rugby unions would be prudent to audit their current support systems for practitioner CPD and implement resources to address identified gaps in coach knowledge, specifically regarding female-specific considerations, that is menstrual cycle and hormonal contraceptive use. A women's rugby specific online educational resource, for example, a podcast series delivering high-quality educational content, delivered from domain experts may be an efficient and cost-effective strategy which employs a platform that is already accepted and utilised by practitioners.

Authors' contributions

The study was conceived and designed by DN, PH, AMN, and BE. Data were collected by DN. Data were analysed by DN, PH, AMN, and BE. Data interpretation and manuscript preparation were undertaken by DN, PH, AMN, and BE. All authors approved the final written version.

Declaration of conflicting interests

The authors have no direct financial conflicts to declare. The lead author engages in extracurricular activities outside of his academic position that could be construed as a conflict of interest, namely hosting of a podcast and participation in delivery of educational courses.

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Supplementary Information

Theme/Subtheme	Quotes
Developmental Stage of Women's Rugby/Definition of Elite	**Coach 2:** '*But even if we were to look at the Six Nations and gather whatever data you want and you get an average of that. How true is that average when you've got a professional team, a semi-professional team and four amateurs?*' '*Whereas I found with senior females, just because they've probably got to that level without having had the years of experience in the gym or that big training age in resistance training*'. **Coach 3:** '*Our camp was about 8 to 10 weeks, that was the longest camp we ever had with the national team and I think now I'm so much more comfortable in saying, OK, these girls can actually start training unsupervised, because before it was us trying to get you know, wherever they are getting supervision, making sure they have access to the gym, making sure that they're doing it safely*'. '*We have just started using GPS on our females*'. '*Because the exposure is limited to the international scene and to the sort of the high performance setup, that makes it difficult for them to keep on the upward curve to make sure that they are ready [to compete at an elite level]*'. '*These girls [international players] only have about three years, you know, experience within a professional set up with programming periodisation. So your limitations, are different because of the exposure time*'. **Coach 6:** '*In female rugby, you might get a player, or it would be more often that you would have got a player who would be like just catapulted into international rugby at a very, very early age*'. '*But like I said, this female game is probably just a little bit far behind that [elite performance]*'. '*You might get a girl who's playing at the top level who physically has no training age at all*'.
Developmental Stage of Women's Rugby/Evolving Nature of Gameplay	**Coach 5:** '*We've seen from twenty thirteen to twenty seventeen World Cups, sorry, twenty fourteen to twenty seventeen as there is only a three year gap to World Cups. The game had changed dramatically and I would hazard a guess in twenty, twenty two. We're going to see that change again. We're going to see a more evolved, more conditioned athlete that will have a higher tolerance to training and just be more conditioned and stronger*'. **Coach 6:** '*Look at premiership rugby or international male rugby, there is more attrition. And the margins are so tight and every single weekend is an absolute physical battle. It's so tough on players. I don't I don't think the cost is quite the same in female rugby at this point in time… [for example if] you're an elite level player in England, the female game, you know, you might play three of your premiership games out of 10 are really tough and then the others are OK. But you might get one or two, which are just a breeze. There's no issues at all. You could train the next day without any problems. You just don't get that in the male game, I don't think so, especially not at the highest level*'. '*So I think that that that process of evolution means that you get to the point where you've created the market, you've created a demand for, you know, getting stronger, getting more powerful over time… It's almost if you if you don't buy into certain elements or if you're just too small, you won't be playing the game at the top level anymore in certain positions, you know, and that's that that's what we talking about with the guys game, is that the female game will go down that same route and certainly has done certainly in my time it went down that route and I suspect it will go further down that route with slightly different physical characteristics being the determining performance as you move forwards*'.

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Theme/Subtheme	Quotes
	Coach 7: '*Rugby is one, you can see those things happening because, you know, physically that the humans are changing*'. '*I think part of that as well is not only a lack of sort of physical capability, you know, a long time ago, but it's also probably the nature of the game as well. So you'd probably get well, I mean, typically was like this and nowadays there's more kicking the female game than there ever has been before, inevitably, because they're just better at doing it and they have more tactical sense to kick it better*'.
Developmental Stage of Women's Rugby/ Professionalism	**Coach 2:** '*I have to remember, they're amateur athletes and there's a lot more that they need to be worrying about. So I just kept it as simple as possible*'. **Coach 3:** '*Because the exposure is limited to the international scene and to the sort of the high performance setup [they require], that makes it difficult for them to keep on the upward curve to make sure that they are ready [to compete at an elite level]*'. '*They have had to walk sometimes, half an hour from the transport that took two hours to get to the stadium just to train for two hours. So that's the reality that I'm dealing with, with national team players. This is the pride and joy of our women's national team*'. **Coach 5:** '*Is the women's game in rugby at a different level to where the men's is? 100%. Are repeating some of the same mistakes that the males would have when they went professional? Probably*'. '*Training age of women's sport is probably well, it's not at the same level as the male game necessarily. So the male gamers had probably more or had a longer period of professionalism that had access to more resources and longer periods of training*'. '*And sometimes the women's program hasn't been as resourced as the men's, so we don't always have as much contact time with the with the athletes and then getting access to facilities*'. **Coach 7:** '*Our women are only professional since two and a half years ago*'. '*The clubs are not professional. So they don't have a strength and conditioning coach for each club…we are working with the with the girls during 13/14 weeks a year, it means they are spending thirty five, thirty six, thirty seven weeks during a season away*'. **Coach 8:** '*I was coaching some lads at the [professional male club] as young as 14/15 four times a week… The problem is I was getting some girls coming to me for [country name] International set up at 24/ 25, maybe even older, who had very little support or even the support they were getting at their clubs wasn't of a standard most 15 year old lads would have been getting just because of the support and the funding behind it*'. '*One of the girls [international player] was a [manual job that is redacted to preserve anonymity], so she had to fit fire doors, emergency fire door for 10 hours in a day, travel 2 hours to training, 2 hours back, had [medical condition that is redacted to preserve anonymity] and then was turning up and not in good shape and they [the management] say she's not working hard enough. And I was literally like I was sat there saying, there is an elephant in the room here is like, where can they do more?*' '*We're getting girls once a weekend every three weeks [for group training]*'.

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Theme/Subtheme	Quotes
Developmental Stage of Women's Rugby/Training Age	**Coach 2:** '*They've probably got to that level [international] without having had the years of experience in the gym or that big training age in resistance training*'.
	Coach 5: '*I think the biggest thing that we would see is the adaptation or the training age as well, probably, adaptation and training age of women's sport is probably well, it's not at the same level as the male game necessarily. So the male gamers had probably more or had a longer period of professionalism that had access to more resources and longer periods of training*'. '*The [male international] has had more exposure to training from earlier age compared to the female athlete. So developing tolerance and ability to train more often, recover well and then train as hard again is probably one of the primary differences we see in the programs. And that's not necessarily a male–female thing, but it's definitely a product of our game currently*'.
	Coach 6: '*I don't think the gender thing is as much of a factor as opposed to the training age…In female rugby, it would be more often that you would have got a player who would be like just catapulted into international rugby at a very, very early age from a from almost school…all of a sudden you end up playing for [International team] with a really physically immature frame*'. '*You might get a girl who's playing at the top level who physically has no training age at all*'. '*You know, a 15 year old rugby player, male, is lifting weights and has done for probably a bit of time or certainly increasing their mastery in their accumulation of loading on the resistance by that age. But I think in typically in female sport, they don't or they haven't historically, just because of the fact that the games or, you know, female sports, certainly at the elite level where players start training properly, lifting weights and what have you, that it's probably not as mature as it is in the male side and also there's probably I think it certainly was in female rugby when I worked there, there is there is a body, a body consciousness around putting on muscle mass*'.
	Coach 8: '*Some of our Six Nations camps were spent teaching some girls to lift… Some girls needed to come in and learn how to push, pull and squat*'. '*Typically, our girls were in worse condition, I'd say, than the guys in terms of a global population. And again, that probably comes down to the under support as opposed to a genuine sex differences*' '*You had untrained girls coming into play at national level… I was coaching some lads at [professional club team] as young as 14/15, four times a week*'. '*That was a huge difference [training age and technical ability]. And that probably determined a lot of the differences between my programming…that probably comes down to the under support as opposed to a genuine sex differences*'.
Physical Preparation/Physiology	**Coach 3:** '*Because of the genetic makeup [females may respond differently], because they don't have that sort of muscle density that a male would have or that speed and power that a male would have*'.
Physical Preparation/Menstrual Cycle	**Coach 2:** '*We'll talk about it [menstrual cycle symptoms] and we will be able to say, OK, well, let's just go with how you're feeling on this. Even if it is that you're only lifting to 70 percent, that's absolutely fine, because we know you're probably not recovering as well*'. '*It's very hard when you're with a team to do that [phase based training]*'.
	Coach 3: '*It's definitely something we can look at, but it's not something that we currently are monitoring*'.
	Coach 4: '*What we do know from the research I think…There is about a 10 day window where technically their muscles, or the joints are a little bit more lax*'.
	Coach 6: '*It might be actually you you're limited from a psychological perspective…you're feeling psychologically low or just feeling like crap, which ultimately I think is that is probably the most impactful element within the menstrual cycle in terms of its impact on training…if you feel really, really bad, then your level of intent, attention to both the cognitive and physical elements of training will be lower*'. '*Practically, I just can't see how that can work [phase based training] when you're trying to run a performance team*'.
Physical Preparation/Hormonal Contraceptives	**Coach 3:** '*I haven't even thought about that [hormonal contraceptives]*'. ''
	Coach 8: '*I don't think enough of our girls took time off the pill… I think if I'm aware you can kind of go two months max on the pill and then just take a month off or it might be two and two…I wouldn't say enough of our girls who were using it would do that*'.

(continued)

(continued)

Theme/Subtheme	Quotes
Physical Preparation/Injuries	**Coach 1:** '*But you do tend to see or there's that knowledge out there of women having greater Q angle, right. So having a little bit higher risk in terms of knee injuries*'.
	Coach 6: '*The large Q-angle and the wider pelvis in tall female athletes does represent a genuine ACL risk*'.
	Coach 8: '*Q-angle, wider hips, post puberty, sort of less development of glute and posterior chain muscles and things like that [may increase injury risk]*'.
Physical Preparation/ Programming	**Coach 1:** '*So exercise selection might not look too different for me*'.
	Coach 2: '*If I was to finish the job I'm currently in with the women's and move into the men's environment, I don't think a lot of what I do would change. As in writing the programme*'.
	Coach 4: '*It's all the same [programming]. It's just a little nuances*'.
Education/Lack of Formal CPD	**Coach 1:** '*No [education regarding the female athlete], we've had general presentations on nutrition, recovery strategy, stress management, obviously all of those other aspects to help improve recoverability and maximize performance and then we've done a ton with physical translation*'. '*And then obviously in today's world, like social media and podcasts and getting information out that way, I think right now that's kind of leading, leading the front from this on this topic anyways [the female athlete]*'.
	Coach 2: '*What sparks my interest in the research is something that I might have heard on a podcast*'.
	Coach 3: '*I listen to a lot of podcasts [for CPD]*' '*We have a fairly good environment that we work at, so I touch on our 7's males conditioning coach, chat to him quite a bit… I prefer the discussions that we need, that we have on a daily basis with the people that are currently in our environment*'.
	Coach 5: '*In short, no [education regarding the female athlete]. It's been a reasonably steep learning curve, I would say, from some of our more qualified, more experienced male coaches who have now found a pathway in women's rugby*'.
	Coach 6: '*Your social media gives you information and point you towards useful, useful pieces of information that you can then explore*'.
Education/Paucity of Research and Implicit Knowledge	**Coach 2:** '*If there was more research…to put ourselves against. What the research says is test match demands?…if there was research done around what a World Cup might look like, great, that's what we need to prepare for…you can't even find out what is average data strength wise, power wise…where does my team sit in comparison to what the average demands are or what the average position specific strength scores are for international female rugby would be?*'
	Coach 4: '*We need more data on high performing [female] athletes…[physical preparation guidelines] were all generated from men*'.

Appendix B: Published article in The Physician and Sportsmedicine

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Prevalence of hormonal contraceptive use and reported side effects of the menstrual cycle and hormonal contraceptive use in powerlifting and rugby

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ORIGINAL RESEARCH

Prevalence of hormonal contraceptive use and reported side effects of the menstrual cycle and hormonal contraceptive use in powerlifting and rugby

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ABSTRACT

Objectives: The prevalence of hormonal contraceptive (HC) use and the associated symptomology of use or nonuse are under-studied in athletic populations, and in particular, in strength and collision sports. This study aimed to investigate the prevalence of hormonal contraceptive use and reported side effects of the menstrual cycle and hormonal contraceptive use in powerlifters and rugby players.
Methods: Competitive female powerlifters and rugby players (aged ≥18 y), representing a strength and a collision sport respectively, completed an anonymous online questionnaire for the purpose of assessing self-reported prevalence of HC use, and symptoms of the menstrual cycle and HC use. Athletes were categorized by sport (powerlifters, n = 149; rugby players, n = 135) in order to conduct a stratified analysis. For open-ended questions, a content analysis was conducted to categorize responses, and frequency analyses were performed.
Results: Current HC use was reported by 51.1% of athletes, with similar prevalence for the two sports (powerlifting, 48.3% vs. rugby, 54.1%, $P = 0.34$). Side effects of the menstrual cycle were reported in 83.5% of non-HC users, with the most common being unspecified cramping (42.4%), headache/migraine (24.5%), and fatigue (24.5%). Side effects were reported in 40.0% of HC users, with the most common being mood changes (17.9%), stomach pain (8.3%) and headaches/migraines (6.9%).
Conclusion: A large proportion of HC users and nonusers in this study experience negative side effects of HC use and the menstrual cycle, respectively. The symptoms experienced by both groups are wide-ranging, with a high degree of variation between individuals. The negative side-effects experienced by HC users and nonusers may have an influence on athletic performance, and this requires future investigation.

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Collision sports; female; menstruation; pain; strength sports

Introduction

The menstrual cycle is an important biological process that occurs between menarche (first menstrual cycle and bleeding) and menopause (permanent cessation of the menstrual cycle), and is characterized in eumenorrheic women by a significant, measurable cyclical variation of endogenous sex hormones, namely estrogen and progesterone [1]. Notably, the shifting hormonal milieu experienced by eumenorrheic women may influence athletic performance at different stages of the menstrual cycle [2,3]. A large proportion of eumenorrheic women experience negative side-effects and symptoms associated with these hormonal fluctuations at different phases of the menstrual cycle [4–6], with a large proportion of athletes (i.e. 50.0% to 84.6%) perceiving the menstrual cycle to have a direct negative effect on their performance in training and competition [7,8].

Hormonal contraceptives (HCs) are defined by the administration of exogenous hormones that affect the endocrine regulation of the female reproductive system, and may inhibit ovulation [9,10]. HC users display a hormonal profile of consistently low endogenous sex hormone concentrations, which induces amenorrhea [11]. HCs are administered by a variety of delivery methods, with oral contraceptives (OC) being the most common delivery method in both general population and athletic cohorts [6,12–14]. HCs are also classified by the hormones employed; combined HCs having both a progestin and estrogenic component, while other HCs having a progestin only component. The differing profiles of HCs may produce variations in their physiological effects and subsequent side-effects, and therefore, may differ in their potential influence on athletic performance [15]. There is equivocal evidence regarding the influence of hormonal contraceptives on exercise performance and chronic training adaptations, with studies reporting HC-use having a positive, negative and neutral influence on adaptation to resistance training [16–21].

Although menstrual function is acknowledged as a critical element of female athlete health, there is a sparsity of research examining the symptomology of the menstrual cycle and prevalence of HC use in athletic populations [3,15]. Prevalence of HC use has been reported to be higher in athletic populations (40.2% to 49.5%) than in the general population (27.0% to 46.0%) [13,22]. The higher prevalence of HC use in athletic populations may be due to the use of HC

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to minimize the perceived negative side-effects of the menstrual cycle and to control menstruation [6,14,23]. For example, one recent study in elite athletes has shown HC users to experience fewer negative side-effects compared to non-HC users [6].

The limited research to date on the symptomology of the menstrual cycle and prevalence of HC use in athletic populations has primarily focused on endurance athletes and non-collision team sports. Few data exist for strength or collision sports. The nature of these sports is unique as the physiological determinants and demands of performance differ greatly to that of sports previously researched. Compared to other sports examined to date, strength or collision sports place greater emphasis of development of strength and lean body mass, and the training demands in terms of energy expenditure would be lower than endurance sports [24–26]. Whether chronic resistance training, or repeated collisions, especially to the torso, influence perceived symptomology is yet to be investigated. Therefore, this study investigated prevalence of HC use and the symptomology of the menstrual cycle or HC use specifically in powerlifting and rugby, as they are representative of sports where the practice of resistance training is highly utilized and attainment of greater lean body mass and high levels of maximal strength are viewed as key performance indicators, but importantly, these sports differ in the presence or absence of collisions and on-field conditioning work.

Materials and methods

Experimental approach to the problem

Competitive female powerlifters or rugby players (aged ≥18 y) completed an anonymous online questionnaire through a link shared via professional networks and social media platforms using a modified questionnaire previously established for the purpose of assessing self-reported symptomology of the menstrual cycle and HC use [6]. The questionnaire was recreated in Google Forms and was open for 3 weeks beginning October 19th, 2020.

Subjects

The study was approved by the Research Ethics Committee at Dublin City University, Ireland (permit: DCUREC/2020/198), in accordance with the Declaration of Helsinki. Subjects provided informed consent through a tick box option in order to proceed to the questionnaire. A convenience sample of 286 athletes accepted the study invitation and completed the survey, with 284 responses included in the final analysis (Figure 1). Inclusion criteria were that subjects had to self-report as being i) a biological female, ii) aged ≥18 y, iii) pre-menopausal, and iv) actively competing in the sport of either powerlifting or rugby.

Data analysis

Statistical analyses were performed using SPSS (Version 24.0, IBM Corp., Armonk, NY). To prevent duplicate data, the database was searched for non-unique dates of births and identical values were visually checked to assess whether the responses were different. Descriptive statistics (i.e. mean, SD, and frequency analysis) were used to display subject characteristics and responses to survey questions providing ordinal data. Athletes were categorized by their sport (powerlifter or rugby player) in order to conduct a stratified analysis. For open-ended questions, a content analysis was conducted to categorize responses, and a frequency analysis performed. Assumptions of normality were checked using the Kolmogorov–Smirnov test. Between-group differences were examined using independent sample t-tests. Pearson's chi-squared (X^2) tests were used to examine the relationship between categorical variables, with Fisher's exact tests used where <80% of expected cell counts were >5 [27]. Duplicate

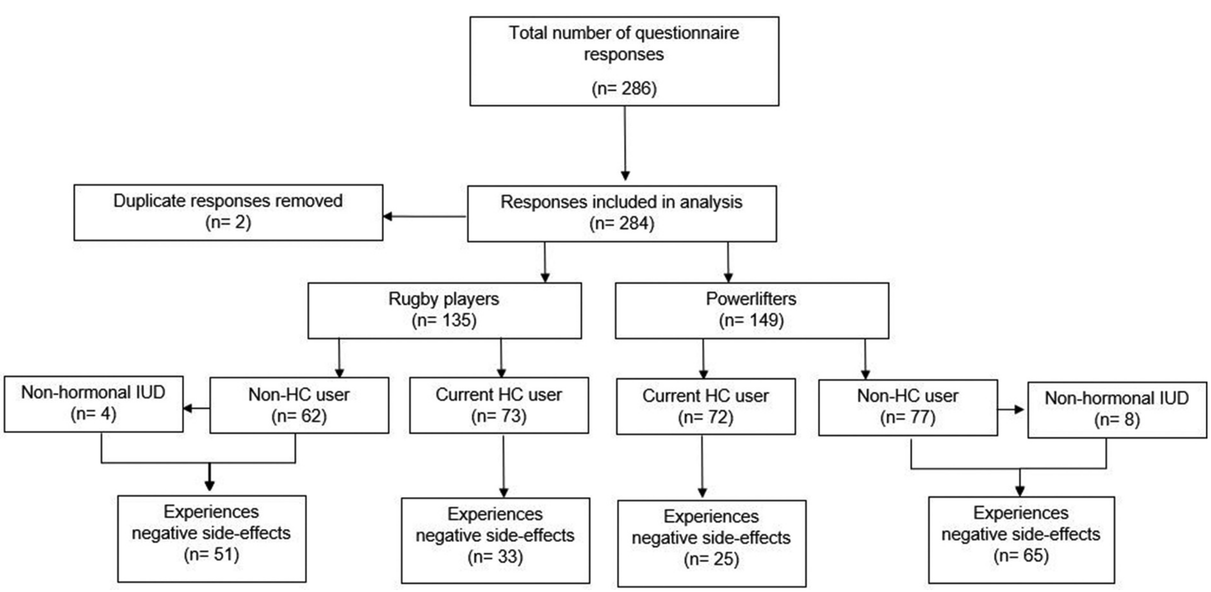

Figure 1. The prevalence of hormonal contraceptive (HC) use and perceived negative side-effects of the menstrual cycle and HC use. IUD, intrauterine device.

responses were identified via visual inspection and removed. Data are represented as mean ± SD, frequencies and percentages, and the threshold for statistical significance was set at $P \leq 0.05$.

Results

Subjects and prevalence of HC use

Subject characteristics are detailed in (Table 1). HC users were significantly older than non-HC users (28.12 ± 7.27 vs. 25.83 ± 5.92 y; $P = 0.004$). Rugby players commenced training (17.39 ± 6.10 vs. 24.78 ± 6.84 y; $P \leq 0.001$) and competing (18.45 ± 5.42 vs. 25.62 ± 6.90 y; $P \leq 0.001$)) in their chosen sport at a significantly younger age that the powerlifters. Subjects consisted predominantly of Europeans (65.8%) and North Americans (19.0%), respectively. The rugby cohort consisted of varying competitive statues ranging from International/National (25.2%) and provincial/club (74.8%), respectively.

An approximately even split between sports was reported [powerlifting, n = 149 (52.5%); rugby, n = 135 (47.5%)]. One hundred and forty-five (51.1%) athletes reported being a current HC user, with the remaining 48.9% not currently using any form of HC, although 4.0% of which were using non-hormonal intrauterine devices (Figure 1). Participation in either sport did not influence HC use ($X^2_1 = 0.9$, $P = 0.34$) with similar prevalence between the two groups observed as 48.3% and 54.1% in powerlifting and rugby, respectively.

Menstrual cycle (non-HC users)

Side effects of the menstrual cycle were reported by 83.5% of non-HC users (Table 2), with the most common being unspecified cramping (42.4%), headache/migraine (24.5%), and fatigue (24.5%). 6.5% of non-HC users described themselves as amenorrheic (defined as having missed more than three consecutive periods). The average menstrual cycle length for the remaining athletes was 29.2 ± 3.3 d, with 69.1% of athletes reporting their menstrual cycle as variable in length. 18.0% and 13.7% of athletes described themselves as having menorrhagia (defined as abnormally heavy bleeding during their period) and being oligomenorrheic (defined as a menstrual cycle length of greater than 35 days), respectively.

Chi-square analysis revealed significant differences between sports for prevalence of unspecified cramp (powerlifting, 33.8% vs. rugby, 53.2%; $X^2_1 = 5.3$, $P = 0.016$), and abdominal pain (powerlifting, 18.2% vs. rugby, 6.5%; $X^2_1 = 4.2$, $P = 0.034$). No other differences were found between the sports in reported side effects or symptomology of the menstrual cycle (all $P > 0.05$).

HC use

Side effects of HC use were reported by 40.0% of HC users (Table 3), with the most common being mood changes (17.9%), abdominal pain (8.3%) and headaches/migraines (6.9%). The most prevalent form of HC delivery reported were oral contraceptives (55.2% of HC users). Length of use

Table 1. Subject characteristics.

	Whole Cohort			Rugby Cohort			Powerlifting Cohort		
	Total (n = 284)	Non-HC Users (n = 139)	HC Users (n = 145)	Total (n = 135)	Non-HC Users (n = 62)	HC Users (n = 73)	Total (n = 149)	Non-HC Users (n = 77)	HC Users (n = 72)
Age (y)	26.95 ± 6.70	28.12 ± 7.27	25.83 ± 5.92*	25.32 ± 5.94†	25.84 ± 6.49	24.88 ± 5.44	28.43 ± 7.02	29.96 ± 7.39	26.79 ± 6.25
Height (m)	1.65 ± 0.08	1.65 ± 0.09	1.66 ± 0.07	1.66 ± 0.09†	1.66 ± 0.11	1.67 ± 0.07	1.64 ± 0.07	1.64 ± 0.07	1.64 ± 0.07
Body mass (kg)	72.86 ± 16.99	73.58 ± 17.52	74.12 ± 16.52	75.67 ± 15.79	75.94 ± 16.56	75.44 ± 15.22	72.22 ± 17.90	71.69 ± 18.14	72.79 ± 17.74
Age began training (y)	21.26 ± 7.47	22.82 ± 7.97	19.77 ± 6.64*	17.39 ± 6.10†	18.73 ± 7.07	16.25 ± 4.90*	24.78 ± 6.84	26.12 ± 7.11	23.35 ± 6.28*
Age began competing (y)	22.21 ± 7.18	23.96 ± 7.37	20.53 ± 6.60*	18.45 ± 5.41†	20.24 ± 5.87	16.93 ± 4.51*	25.62 ± 6.90	29.96 ± 7.11	24.18 ± 6.39*
Weekly training duration (h)	7.62 ± 3.52	7.80 ± 3.54	7.44 ± 3.52	5.8 ± 2.97†	5.66 ± 2.48	5.92 ± 3.34	9.26 ± 3.17	9.52 ± 3.33	8.99 ± 2.99

*indicates a significant difference between hormonal contraceptive (HC) user and non-HC users within the indicated cohort ($P \leq 0.05$); †indicates a significant difference between rugby and powerlifting for 'Total' column ($P \leq 0.05$)

Table 2. Frequency analysis of side effects in non-hormonal contraceptive users (n = 139).

Symptom	Frequency	Prevalence (%)
Unspecified cramp	59	42.4
Headache/migraine	34	24.5
Tiredness/fatigue/lethargy	34	24.5
Mood changes	25	18.0
Back pain	22	15.8
Stomach pain/abdominal cramps	18	12.9
Bloating	14	10.1
Nausea/sickness /vomiting	12	8.6
Sore breasts	11	7.9
Irritability	10	7.2
Increased appetite	7	5.0
Unspecified pain	6	4.3
Diarrhoea/digestive issues	6	4.3
Poor skin	5	3.6
Sleep disturbances	5	3.6
Hot flushes/increased sweating	4	2.9
Decreased appetite	4	2.9
Dizzy/lightheaded/lack of coordination	3	2.2
Muscle ache	3	2.2
Weakness	3	2.2
Leg discomfort	2	1.4
Constipation	2	1.4
Problems with exercise	2	1.4
Flustered/lack of focus	2	1.4
Pre-menstrual syndrome	2	1.4
Heavy bleeding	1	0.7
Increased heart rate	1	0.7
Vaginal pain	1	0.7
Shortness of breath	1	0.7
Colic	1	0.7
Cold chills	1	0.7
Excessive salivating	1	0.7
Weight gain	1	0.7
Increased libido	1	0.7
Increased energy	1	0.7
Water retention	1	0.7
Excessive thirst	1	0.7
Increased nighttime urination	1	0.7

Table 3. Frequency analysis of side effects in hormonal contraceptive users (n = 145).

Symptom	Frequency	Prevalence (%)
Mood changes	26	17.9
Stomach pain	12	8.3
Headaches/migraines	10	6.9
Poor skin	8	5.5
Tiredness/fatigue/lethargy	8	5.5
Bloating	7	4.8
Weight gain	6	4.1
Breast Issues (swollen or sore)	5	3.4
Spotting	5	3.4
Irregular period	4	2.8
Loss of period	4	2.8
Negative effect on performance	4	2.8
Nausea/sickness/vomiting	2	1.4
Water retention	2	1.4
Increased appetite	2	1.4
Back pain	2	1.4
Heavier period	2	1.4
Decreased appetite	2	1.4
Reduced libido	2	1.4
Altered cycle length	1	0.7
Painful period	1	0.7
Pre-menstrual syndrome	1	0.7
Dizziness	1	0.7
Increased libido	1	0.7
Lighter bleeding/period	1	0.7

Note: The term 'period' is used in this Table consistent with the terms used by the respondents, but we acknowledge that many athletes use 'period' incorrectly to describe the withdrawal bleed experienced with HC use. Please see main text for further discussion.

ranged from ≤6 months (n = 5) to ≥5 years (n = 41). Never engaging in the 7 'pill-free' days each cycle was reported by 30.0% of oral HC users, while 45.0% reported always observing the 7 'pill-free' days.

Chi-square analysis revealed a significant difference between sports for prevalence of mood changes (powerlifting, 11.1% vs. rugby, 24.7%; $X^2_1 = 4.5$, $P = 0.027$). No other differences were found between the sports in reported side effects or symptomology of HC use (all $P > 0.05$).

Discussion

This investigation of the symptomology of the menstrual cycle and prevalence of HC use in athletic populations is the largest to date in a rugby cohort, and the only study in powerlifters. This study thereby provides new data for sports with a considerable demand for strength and power component, and additionally those with collision events. Approximately half of the female athletes in this study were current HC users, and participation in powerlifting or rugby did not result in a difference in prevalence of use. HC users and non-HC users alike experienced varying degrees of negative side-effects of HC use and of the menstrual cycle, with side effects being greater in non-HC users regardless of sport.

The prevalence of HC use of 51.1% in this athlete cohort is higher than that previously reported for the general population, which varies in the reported prevalence of use (21.2% to 46.0%) [12,13,28], and is similar to the prevalence of 49.5% recently reported in elite female athletes from a range of sports [6]. As previously stated, the greater prevalence of HC use in athletic populations may be due partly to the perception by athletes that they can better predict and control menstruation, and attempting to avoid menstruation during periods of competition or training of heightened importance [6,14]. An important related point, especially given the high prevalence of HC use in athletes, is that many athletes equate the withdrawal bleed experienced during the 'pill-free' days of HC use with a menstrual bleed. This confusion may lead to athletes and coaches alike assuming an athlete is eumenorrheic when HC use may be masking menstrual dysfunction [29]. Given that menstrual dysfunction is an important indicator of Relative Energy Deficiency in Sport (RED-S) [30], and the recent call for positive communication around the menstrual cycle in this context [31,32], increasing awareness of this issue of 'masking' may be important amongst athletes and practitioners.

A large proportion (83.5%) of non-HC users experienced negative side-effects of the menstrual cycle with the most cited symptoms being cramping, headache/migraine and fatigue. Athlete type (powerlifter vs. rugby player) had an influence on the reported symptoms, with rugby players reporting higher incidence of '*unspecified cramp*' (53.2% vs. 33.8%), and powerlifters reporting higher incidence of '*abdominal cramp*' 18.2% vs. 6.5%). Presently, we attribute this finding as an artifact of the terminology of the questionnaire coupled with the content analysis employed. When an athlete reported cramp as a symptom, but did not directly state it as an abdominal cramp, it was categorized as '*unspecified cramp*.'

When the respective data for '*unspecified cramp*' and '*abdominal cramp*' are combined for each sport, there is no difference between sports. The prevalence of reported negative side-effects of the menstrual cycle in non-HC users are similar to those previously reported (74 to 93%) [5,6,8,33], indicating that the focus on strength training, with or without the presence of collision events, in these sports does not have a unique influence on symptom prevalence for the menstrual cycle.

HC users had lower prevalence of negative side-effects (40.0%) of HC use, when compared with symptom prevalence for the menstrual cycle in non-HC users in this study. The most common reported side-effect of HC use was mood changes (e.g. increased anxiety, depressive symptoms, or increased irritability). With 17.9% of HC users reporting this symptom, this is almost identical to the prevalence of the same symptom in the non-HC users (18.0%). Athlete type was shown to have a significant influence on mood changes, with the 24.7% incidence in rugby players being higher than the 11.1% in powerlifters. A physiological basis to explain this finding is lacking at present, but a speculative explanation may be that the individual versus team-based nature of the respective sports could influence the athlete's awareness and perception of this symptom. Alternatively, this may be an incidental finding.

The data presented in this study highlight the importance for athletes and coaches to have an open dialogue regarding menstrual cycle function and HC use. Both HC and non-HC users experience negative side-effects, which may have an influence on performance in training and competition [3,8,15,34]. We recommend that coaches adopt an accommodating culture in which flexibility may be permitted to accommodate for those athletes experiencing severe symptoms of the menstrual cycle or HC use.

This study collected responses representing a wide, geographical spread, but a limitation is that we did not record the ethnicity of the respondents. Whether ethnicity influences the physiological response to, and symptoms perceived by HC and non-HC using athletes is yet to be investigated. Another limitation of this study is that specific details relating to contraceptive use such as the type of OC, brand name, progestins used, were not collected, meaning that a deeper analysis of the association of symptoms with these variables could not be performed. Such an analysis would be of interest in future studies. Future studies should also consider the effects of the length of use of HCs on aspects of health, training and performance, as 28.2% of HC users in this study have used HC continually for ≥5 years. These long-term implications are not yet understood, and are particularly important given that a third of respondents in this study do not follow best practice guidelines for HC use by observing the monthly '*pill-free*' time period.

In conclusion, approximately half of the athletes in this study used HCs, and a large proportion of HC users and nonusers experience negative side-effects of HC use, and of the menstrual cycle, respectively. The symptomology experienced by HC and non-HC users is wide-ranging, with a high degree of variation between individuals, but prevalence in these strength and collision sport athletes is broadly consistent with that reported in other athletes.

Authorship

The study was conceived and designed by DN, KJES and BE. Data were collected by DN. Data were analyzed by DN and BE. Data interpretation and manuscript preparation were undertaken by DN, KJES and BE. All authors approved the final written version.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix C: Published article in the Journal of Functional Morphology and Kinesiology

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MDPI

Article

Physical Match Demands of International Women's Rugby Union: A Three-Year Longitudinal Analysis of a Team Competing in The Women's Six Nations Championship

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Abstract: There is a paucity of studies describing the physical match demands of elite international women's rugby union, which limits coaches' ability to effectively prepare players for the physical demands required to compete at the elite level. Global positioning system technologies were used to measure the physical match demands of 53 international female rugby union players during three consecutive Women's Six Nations Championships (2020–2022), resulting in 260 individual match performances. Mixed-linear modelling was used to investigate differences in physical match demands between positions. Significant effects ($p < 0.05$) of the position were observed for all variables, with the exception of relative distances (m.min^{-1}) at velocities of 1.01–3.00 m·s^{-1} ($p = 0.094$) and 3.01–5.00 m·s^{-1} ($p = 0.216$). This study provides valuable data on the physical match demands of elite international women's rugby union match play that may aid practitioners in the physical preparation of players to compete at this level. Training methodologies for elite-level female rugby union players should consider the unique demands across positional groups with specific considerations of high-velocity running and collision frequency.

Keywords: conditioning; female athlete; running; team sport

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1. Introduction

The women's rugby union has experienced significant growth in participation numbers in recent years, with approximately 1 million active players registered globally in 2021 [1]. Despite this growth and the professionalization of the male game that began almost three decades ago, the majority of "elite" (international-level) female players in the modern era have participated as amateurs [2]. The Women's Six Nations, existing in its current format since 2002, is an annual international rugby union competition contested among six top-ranked European teams (UK, France, Ireland, Italy, Scotland, and Wales) [3]. From 2016 onwards, the decision by specific nations to provide professional contracts to their international players has resulted in the Women's Six Nations Championship simultaneously consisting of professional, semiprofessional, and amateur teams.

Rugby union can be described as an invasion field-based team sport consisting of intermittent bouts of high-intensity efforts (i.e., running, sprinting, tackling, rucking, mauling, and scrummaging) and periods of lower-intensity activity (i.e., walking, jogging, and resting) [4]. The improved sophistication and increased use of global positioning systems (GPS) technology in rugby union has enabled the in-depth analysis of the physical demands of match play [5,6], i.e., running distances, velocities, accelerations, decelerations, and related variables. Modern GPS technology also provides valid measures of collision events in rugby union [7]. These data may provide practitioners with useful metrics regarding physical match demands and monitoring training load, thereby aiding in the design of appropriate physical conditioning programs to improve tolerance to the demands of match play, potentially improving performance and reducing injury risk [8,9]. The match demands of men's rugby union are well-documented across both playing level [4,10,11] and age grades [12]. A paucity of studies describing match demands of women's rugby union exists [13], particularly at the international level, with previous studies using lower-ranked teams and small samples [14,15]. The most comprehensive analysis of the physical demands of women's international rugby union to date reported differences between playing positions in high-velocity running (>5.5 m·s^{-1}), accelerations, decelerations, and collisions [16]. Notably, this cohort ranked in the top 2 teams globally for the entirety of the data collection period, with several years consisting of professional players. The inclusion of data from professional players may limit the extrapolation of these findings to the wider international women's rugby union population, as the majority of players are amateur. The heterogeneity of the methodology employed in previous studies of international cohorts [14–16], specifically the inclusion/exclusion criteria for match files and the used velocity thresholds, limit further comparison and synthesis of the existing literature.

This study provides the three-year longitudinal analysis of physical match demands of an elite, amateur, women's international rugby union team competing in the Women's Six Nations Championship. The study also investigates the influence of playing position, which was hypothesized to have a significant effect on physical match demands.

2. Materials and Methods

Following institutional ethical approval (REF: DCUREC/2022/012), a three-year longitudinal analysis of the physical match demands of the Women's Six Nations Championship was conducted between 2020 and 2022 inclusive. A total of 53 players from a single team generated 260 match files from 12 matches (mean individual match files: 3.9 ± 2.6; median: 3; range: 1–12) across the three successive campaigns. Individual positions were categorized into seven groups: front-row (FR; n = 11, prop and hooker), second-row (2R, n = 7), back-row (BR; n = 9, flanker and number eight), scrum-half (SH, n = 5), fly-half (FH, n = 5), center (C, n = 5), back-three (B3; n = 11, winger and full-back).

All matches took place between the hours of 12:00 and 22:00. Physical match demands were quantified using APEX GPS units (STATSports Apex; STATSports, Newry, Ireland), which were switched on and fitted at least 15 min prior to the start of match play which is recommended to improve connectivity [17]. These devices demonstrate typical measurement error of <5% in coefficient of variation (CV), with close (<2% CV) comparisons to sport-specific variable measurements i.e., distance covered and peak velocity [18,19]. Files were downloaded into the manufacturer's software for analysis, with warm-up and half-time periods removed post hoc. All GPS files were included in the analysis, regardless of time on pitch (mean: 69.23 ± 32.49 min; median: 77.97 min; range: 1.75–123.48 min).

The analyzed variables were: total distance, distances covered at <1.00, 1.01–3, 3.01–5.00, 5.01–5.50, and >5.50 m·s^{-1}. Total collisions (contacts >8 g) were also recorded. Maximal velocity was determined via a 40 m sprint test conducted in the preseason periods using the SmartSpeed single-beam timing gates system (VALD, Brisbane, Australia). Average velocity achieved from the 30–40 m split was computed as the maximal velocity and manually imported to the manufacturer's software. Maximal velocity was automatically increased by the manufacturer's software in the event of an individual achieving velocities greater than those assigned on three subsequent occasions during match play, with the average of these three higher velocities becoming the updated maximal velocity. Acceleration and deceleration metrics were recorded, but not included in the final analysis due to high levels of error for these specific metrics [20]. All variables are expressed in absolute terms (m) and relative to playing time (m.min^{-1}). Arbitrary thresholds were set to align with, and allow for comparison, where possible, to previous studies on female rugby [14–16,21,22].

Statistical analysis was completed using the Statistical Package for the Social Sciences SPSS v.27, IBM, Chicago, IL, USA). Data are presented as mean ± standard deviation (SD) unless otherwise stated. All variables were log transformed prior to statistical analysis.

Differences in the relative physical demands between playing positions were examined using a series of linear mixed models. Playing seasons (2020, 2021, and 2022) and position were treated as the fixed effects, and individual players were treated as a random effect. Significant fixed effects were probed using post hoc Bonferroni comparisons. Due to variations in minutes played across positions and matches, statistical analysis was only performed on data for relative to playing time (m.min^{-1}), but not absolute distances (m). All statistical analyses accepted significance at $p < 0.05$.

3. Results

Physical match demands are reported in Tables 1–3. The pairwise comparisons of relative physical match demands separated by playing position are shown in Table 3. Significant effects of the position were observed for all variables, with the exception of relative distances at velocities of 1.01–3.00 and 3.01–5.00 m·s^{-1}.

Table 1. Physical match demands of match play for a squad of international female rugby union players during three consecutive years of the Women's Six Nations Championship.

	Mean
Time played	69.2 ± 32.5
Total distance (m)	4177 ± 2066
Relative distance (m.min^{-1})	59.6 ± 8.68
Peak velocity achieved (m·s^{-1})	6.76 ± 0.97
Percentage of maximum velocity achieved (%)	85.7 ± 8.95
Total distance < 1 m·s^{-1} (m)	741 ± 378
Relative distance < 1 m·s^{-1} (m.min^{-1})	10.6 ± 1.70
Total distance at 1.01–3.00 m·s^{-1} (m)	2076 ± 1036
Relative distance at 1.01–3.00 m·s^{-1} (m.min^{-1})	29.5 ± 4.53
Total distance at 3.01–5.00 m·s^{-1} (m)	1157 ± 637
Relative distance at 3.01–5.00 m·s^{-1} (m.min^{-1})	16.6 ± 5.80
Total distance at 5.01–5.50 m·s^{-1} (m)	97.0 ± 75.8
Relative distance at 5.01–5.50 m·s^{-1} (m.min^{-1})	1.40 ± 0.89
Total distance at > 5.50 m·s^{-1} (m)	106 ± 126
Relative distance at > 5.50 m·s^{-1} (m.min^{-1})	1.51 ± 1.71
Total collisions (n)	31.6 ± 39.3
Collisions per min	0.46 ± 0.48

Table 2. Positional differences in the *absolute* physical match demands of match play for a squad of international female rugby union players during three consecutive years of the Women's Six Nations Championship.

	FR (n = 62)	**2R (n = 35)**	**BR (n = 47)**	**SH (n = 28)**	**FH (n = 13)**	**C (n = 28)**	**B3 (n = 47)**
Time played (min)	58.1 ± 31.8	74.7 ± 28.6	73.2 ± 33.2	56.2 ± 33.3	63.6 ± 33.9	77.8 ± 35.2	80.2 ± 27.0
Total distance (m)	3232 ± 1812	4490 ± 1779	4118 ± 1967	3541 ± 2203	4231 ± 2362	4917 ± 2219	5173 ± 1842
Total distance < 1 m·s^{-1} (m)	542.0 ± 294	731 ± 282	849 ± 414	564 ± 350	725 ± 392	887 ± 408	925 ± 345

Table 2. *Cont.*

	FR (n = 62)	2R (n = 35)	BR (n = 47)	SH (n = 28)	FH (n = 13)	C (n = 28)	B3 (n = 47)
Total distance at 1.01–3.00 $m \cdot s^{-1}$ (m)	1740 ± 987	2197 ± 905	2086 ± 1045	1709 ± 1108	2032 ± 1095	2434 ± 1114	2438 ± 912
Total distance at 3.01–5.00 $m \cdot s^{-1}$ (m)	863 ± 579	1432 ± 619	1057 ± 510	1100 ± 754	1213 ± 759	1306 ± 614	1367 ± 588
Total distance at 5.01–5.50 $m \cdot s^{-1}$ (m)	50.3 ± 54.7	80.4 ± 64.0	75.3 ± 50.0	92.4 ± 73.1	136 ± 91.7	133 ± 68.0	163 ± 74.3
Total distance at > 5.50 $m \cdot s^{-1}$ (m)	36.1 ± 57.6	49.8 ± 48.8	49.7 ± 44.5	75.5 ± 73.2	125 ± 96.7	158 ± 118	280 ± 149
Total collisions (n)	24.7 ± 29.2	24.0 ± 28.1	67.6 ± 56.0	20.1 ± 29.6	17.2 ± 25.7	26.3 ± 29.5	24.2 ± 31.8

FR = front row, 2R = second row, BR = back row, SH = scrum half, FH = fly half, C = center, B3 = back three.

Table 3. Positional differences with pairwise comparisons in the *relative* physical match demands of match play for a squad of international female rugby union players during three consecutive years of the Women's Six Nations Championship.

	FR (n = 62)	2R (n = 35)	BR (n = 47)	SH (n = 28)	FH (n = 13)	C (n = 28)	B3 (n = 47)
Relative distance ($m.min^{-1}$)	55.0 ± 7.58 ^{g}	59.4 ± 5.55	56.3 ± 8.63 ^{g}	61.3 ± 11.9	64.5 ± 7.31	63.5 ± 4.52	64.4 ± 7.76 ^{a,c}
Peak velocity achieved ($m \cdot s^{-1}$)	6.14 ± 0.77 ^{f,g}	6.32 ± 0.54 ^{g}	6.51 ± 0.96 ^{g}	6.56 ± 0.71 ^{g}	6.95 ± 0.68	7.27 ± 0.81 ^{a}	7.92 ± 0.56 ^{a,b,c,d}
Percentage of maximum velocity achieved (%)	82.6 ± 8.18 ^{f,g}	83.9 ± 6.60 ^{g}	82.9 ± 11.4 ^{g}	84.8 ± 9.22	86.8 ± 7.97	90.2 ± 7.10 ^{a}	91.4 ± 5.77 ^{a,b,c}
Relative distance < 1 $m \cdot s^{-1}$ ($m.min^{-1}$)	9.47 ± 1.21 ^{f,g}	9.85 ± 0.80	11.4 ± 1.94	10.2 ± 1.45	11.6 ± 1.19	11.6 ± 1.38 ^{a}	11.5 ± 1.67 ^{a}
Relative distance at 1.01–3.00 $m \cdot s^{-1}$ ($m.min^{-1}$)	29.6 ± 4.63	29.0 ± 3.58	27.7 ± 5.18	29.0 ± 5.12	31.1 ± 3.88	31.4 ± 3.23	30.2 ± 4.21
Relative distance at 3.01–5.00 $m \cdot s^{-1}$ ($m.min^{-1}$)	14.6 ± 5.39	18.7 ± 3.65	15.6 ± 7.92	18.9 ± 7.46	17.7 ± 5.38	16.9 ± 2.69	16.9 ± 4.48
Relative distance at 5.01–5.50 $m \cdot s^{-1}$ ($m.min^{-1}$)	0.85 ± 0.81 ^{d,e,f,g}	1.14 ± 0.92 ^{e,g}	1.05 ± 0.52 ^{f,g}	1.65 ± 0.95 ^{a}	2.07 ± 0.62 ^{a,b}	1.74 ± 0.63 ^{a,c}	2.09 ± 0.73 ^{a,b,c}
Relative distance at > 5.50 $m \cdot s^{-1}$ ($m.min^{-1}$)	0.55 ± 0.76 ^{e,f,g}	0.79 ± 0.89 ^{g}	0.66 ± 0.62 ^{g}	1.60 ± 1.67	2.01 ± 1.24 ^{a}	1.92 ± 1.12 ^{a}	3.73 ± 2.10 ^{a,b,c}

FR = front row, 2R = second row, BR = back row, SH = scrum half, FH = fly half, C = center, B3 = back three. $^{a, b, c, d, e, f, g}$ significantly different from FR, 2R, BR, SH, FH, C, and B3, respectively.

4. Discussion

This study provides valuable descriptive data regarding the physical match demands of international women's rugby union while also investigating the influence of playing position on relative demands of match play. Similar to previous studies [15,16,21], playing position had a significant effect on physical match demands in the present study, with the exception of relative distances at velocities of 1.01–3.00 and 3.01–5.00 $m \cdot s^{-1}$. Total distance separated by position in the present study was 3232–5173 m, which is similar to previously reported top-ranked international female rugby union players (3240–5283 m) [16], but lower than the 5784 and 5820 m reported in other international cohorts [14,15]. This distance is also lower than the 4982 m reported for English premiership players [22]. The higher absolute values reported for other international cohorts were likely due to the decision to only include match files from players who took part in ≥60 min of match play [15,22] or complete match files [14] compared to the present study, which included all match files regardless of playing time. Relative distance for the present cohort (59.6 $m.min^{-1}$)

was lower than that previously reported in international and club-level female rugby (65.9–68.3 m.min^{-1}) [14,16,21]. Given that peak velocity achieved in the present study (6.8 m.min^{-1}) was higher than that previously reported (6.1 m.min^{-1}) [14], and collision frequency (0.46 collisions per min) was also higher than that previously reported [16], the lower relative distance in the present study may have been due to contextual match constraints, i.e., technical and tactical factors.

Total distance covered at > 5.5 m·s^{-1} accounted for ~2.5% of the total distance, which was higher than the ~1.2% previously reported in a similarly ranked cohort [14], but similar to the ~2.7% reported for a top-ranked team [16]. Distance covered at high velocities, rather than the absolute distance covered during match play was posited as a differentiating factor between top- and lower-ranked teams [23]. This has not yet been found in female rugby union and may warrant further investigation. Due to the similarities observed in the physical match demands of the current cohort to those of a top-ranked professional team, it may be that factors other than physical match demands are the key differentiating factors between top- and lower-ranked teams, i.e., technical and tactical ability.

Akin to previous reports [15,16], FR and SH covered the least total distances, but similar to these studies, this observation can be attributed to substitution strategy, with FR and SH playing fewer minutes than those in other positions. FR displayed lower relative distances and peak velocities than those of backs (C and B3), which is consistent with that previously reported in international cohorts [16]. Relative running demands are similar between the back positional groups, with no differences found apart from SH displaying lower peak velocity achieved in match play than that in B3. Similarly, no differences were found between the different forward positions (FR, 2R, and BR) for relative demands. The current cohort displayed a higher homogeneity of relative demands across positional groups (forwards and backs) than that previously reported [15,16], but this may be attributable to the larger number of match files used in those studies.

Collision frequency by position (ranging from 0.23 to 0.89 collisions per min) in the present study was higher than that previously reported in women's international rugby union (0.17 to 0.33 collisions per min) [16] and in male rugby union (0.18 to 0.44 collisions per min) [7]. These differences may have been the result of specific tactical approaches adopted by teams during these specific matches. Women's rugby union has adopted more possession-driven attacking tactics compared to increased kicking frequency in the male game [24]. This open and continuous style of play in the female game may explain the increased collision frequency. There is also a large difference in sample size and number of matches captured in the present study compared to previous analysis of women's international rugby union (n = 260, 12 matches vs. n = 967, 53 matches) [16]. This likely resulted in the latter cohort being exposed to a wider range of teams of varying tactical strategy and technical ability, which may explain the differences in collision frequency reported.

An important consideration is that all data presented in the present study were collected across the 2020, 2021, and 2022 championships, which coincided with the COVID-19 global pandemic. The pandemic caused a significant disruption to the normal functioning of the Women's Six Nations Championship including delays, the rescheduling of matches, the cancellation of matches, and the restriction of spectator attendance. COVID-19 restrictions and public health policies may have also impacted training scheduling and player availability.

There are several limitations to this study; however, they are not unique to this investigation, but rather characteristic of this research area. The present study utilized data from only one team, which may have limited its application to other elite teams given the complex and contextual nature of match demands [25]. Inconsistency in methodological approaches across studies specifically regarding inclusion/exclusion criteria and application of velocity thresholds hinders direct comparison. Classification issues due to a lack of consensus regarding velocity thresholds may be compounded further in female team sports due to limited research [26]. The reported data describe the physical match demands, but do not account for the influence of differing tactical strategies adopted by the team and/or their opposition; thus, these data should be interpreted with an appreciation of relevant contextual factors, e.g., weather conditions, the level of opposition, playing style, and match significance. Ball-in-play data were not collected in the present study, which could significantly influence the relative intensity and collision frequency [27]. Practitioners should, therefore, be cognizant of potential contextual factors when interpreting the data provided in this study.

Since the completion of this investigation, it has been announced that the international team, which is the focus of the present study, intend to offer a number of professional contracts to players, effectively transitioning into a semiprofessional environment [28]. All other amateur teams competing in the Women's Six Nations Championship have recently announced similar intentions [29–31]; thus, the 2023 Women's Six Nations Championship, for the first time, will consist of only professional and semiprofessional teams rather than also including amateur teams. Future research should investigate factors other than physical match demands that differentiate high- and lower-ranked teams.

5. Conclusions

The present study provided the descriptive data of the physical demands of match play from an elite, amateur, women's international rugby union team competing in the Women's Six Nations Championship across a three-year period. Total running demands were similar to those previously reported in other international cohorts employing similar methodology, but the number of collisions per minute was higher than that previously reported in similar cohorts. Differences in the physical demands were found between positions, and practitioners should be aware of the broad demands of match play and position-specific differences when designing training programs. Training methodologies for elite-level female rugby union players should consider the unique demands across positional groups with specific consideration of high-velocity running and collision frequency.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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Appendix D: Published Article in Sports Medicine

TITLE

The effect of hormonal contraceptive use on skeletal muscle hypertrophy, power, and strength adaptations to resistance exercise training: a systematic review and multilevel meta-analysis

RUNNING TITLE

Hormonal contraceptives and resistance exercise training

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ABSTRACT

Resistance exercise training is widely used by general and athletic populations to increase skeletal muscle hypertrophy, power, and strength. Endogenous sex hormones influence various bodily functions, including possibly exercise performance, and may influence adaptive changes in response to exercise training. Hormonal contraceptive (HC) use modulates the profile of endogenous sex hormones, and therefore, there is increasing interest in the impact, if any, of HC use on adaptive responses to resistance exercise training. This study aimed to provide a quantitative synthesis of the effect of HC use on skeletal muscle hypertrophy, power, and strength adaptations in response to resistance exercise training. A systematic review with meta-analysis was conducted on experimental studies conducted before January 2023. The search using the online databases PUBMED, SPORTDiscus, Web of Science, Embase, and other supplementary search strategies yielded 4,567 articles, with eight articles (54 effects and 325 participants) meeting the inclusion criteria. All included studies investigated the influence of oral contraceptive pills (OCP), with no study including participants using other forms of HC. The articles were analysed using a meta-analytic multilevel maximum likelihood estimator model. The results indicate that OCP use does not have a significant effect on hypertrophy (g = 0.00, CI 95% [-0.12, 0.13], t = *0.08*, p = 0.94), power (g = -0.04, CI 95% [-0.93, 0.84], t =*-0.29*, p = 0.80), or strength (g = 0.10, CI 95% [-0.08, 0.28], t =*1.48*, p = 0.20). Based on the current analysis, there is no evidence-based rationale to advocate for or against the use of OCPs in females partaking in resistance exercise training to increase hypertrophy, power, and/or strength. Rather, an individualised approach considering an individual's response to OCPs, their reasons for use, and menstrual cycle history may be more appropriate.

Keywords

female; lean body mass; oestrogen; oral contraceptive pill; progestin;

Key points

- When comparing OCP users to non-users, OCP use has no significant effect on skeletal muscle hypertrophy, power, or strength adaptations in response to resistance exercise training.
- Based on the current analysis, there is no evidence-based rationale to advocate for or against the use of OCPs in females partaking in resistance exercise training to increase hypertrophy, power, and/or strength.

- To date, studies investigating the influence of HCs on adaptations to resistance exercise training have exclusively investigated OCPs, and future research should also examine the potential influence of different HC types.

1. Introduction:

Resistance exercise training is strongly encouraged for the general population because of its myriad of associated health benefits [1] and is widely used by athletic populations as part of a comprehensive athletic development training program [2]. Resistance exercise training elicits morphological (i.e., increased muscle fibre/whole muscle cross-sectional area, change in muscle fibre pennation angle, and increases in the proportion of non-contractile tissues) and neurological (i.e., increased motor unit activation, firing frequency, and synchrony of high threshold unit) adaptations which contribute to changes in skeletal muscle hypertrophy, power and strength [3]. Higher levels of muscle strength are associated with superior force-time characteristics (e.g., rate of force development and increased external mechanical power), general sport-related skill performance (e.g., jumping, sprinting, and change of direction), and a decreased risk of injury [4].

Hormonal contraceptives (HCs), which involve the administration of exogenous hormones that affect endocrine regulation of the female reproductive system [5,6], are used by a sizeable proportion of individuals in both general (~28–43%) [7,8] and athletic (~40–51%) [9–11] populations. HCs are classified according to the hormones employed; combined HCs have both oestrogenic and progestin components, whereas other HCs have a progestin-only component. HCs are also administered using various delivery methods, with the oral contraceptive pill (OCP) being the most commonly used form [8,12]. Combined OCPs reduce endogenous concentrations of 17 beta oestradiol and progesterone (compared to the mid-luteal phase of the menstrual cycle), acting via negative feedback on the gonadotrophic hormones, chronically downregulating the hypothalamic-pituitary-ovarian axis [12]. Dependent on if, and how, the dosages of exogenous hormones vary across the OCP cycle, the combined OCPs can be monophasic (i.e., consistent dosage), biphasic (i.e., two levels of dosage), or triphasic (i.e., three levels of dosage), and are also are classified by "generation", categorised by the form of progestin used [13].

Endogenous sex hormones influence various bodily functions and may also influence exercise performance [14]. HC use has equivocal effects on acute measures of athletic performance [12], yet the majority of literature to date is of low quality, with small sample sizes, lack of standardisation, and inadequate familiarisation, among the important issues that limit interpretation. Relatedly, the impact of HC use on adaptive responses to resistance exercise training has been the subject of increasing interest, with positive (molecular markers) [15], negative (hypertrophy, strength, inflammation) [16–18], and neutral (hypertrophy, strength, power) [19–25] outcomes being observed in HC users compared to non-users. Lack of consistent findings on the influence of exogenous hormones on resistance exercise training adaptations contributes to confusion in females and those that work with them, when trying to make an informed decision on whether or not hormonal contraception is likely to impact athletic performance and/or training adaptations. Given the mixed findings to date, and absence of evidence-based recommendations exist for sportswomen and practitioners who work with them, this review aimed to investigate the influence of HCs on skeletal muscle hypertrophy, power, and strength adaptations in response to resistance exercise training.

2. Methods

2.1. Literature Search and Management

All items in this protocol correspond with the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols Statement (PRISMA-P; [26]; See Electronic Supplementary Material) The review protocol was registered on PROSPERO (ID number and hyperlink: CRD42022365677) on December 3rd, 2022. The literature used in this meta-analysis was obtained before January 12th, 2023, from the following databases; PUBMED, SPORTDiscus, Web of Science, and Embase. The first author (DN) gathered the literature from the databases using the following search string for all databases: *("contraceptive" OR "contraceptives" OR "hormonal" OR "birth control")AND ("exercise" OR "resistance training" OR "resistance exercise training" OR "hypertrophy training" OR "weightlifting" OR "bodybuilding" OR "athletic training" OR "strength training" OR "power training" OR "plyometric training" OR "jump training" OR "physical training") AND ("strength" OR "hypertrophy" OR "mobility" OR "power" OR "sprint" OR "rate of force development" OR "RFD" OR "speed" OR "jump" OR "stiffness" OR "reactive strength index" OR "dynamic strength index" OR "flexibility" OR "RSI" OR "DSI" OR "EUR" OR "eccentric utilisation ratio" OR "eccentric utilization ratio" OR "tendon" OR "ligament").*

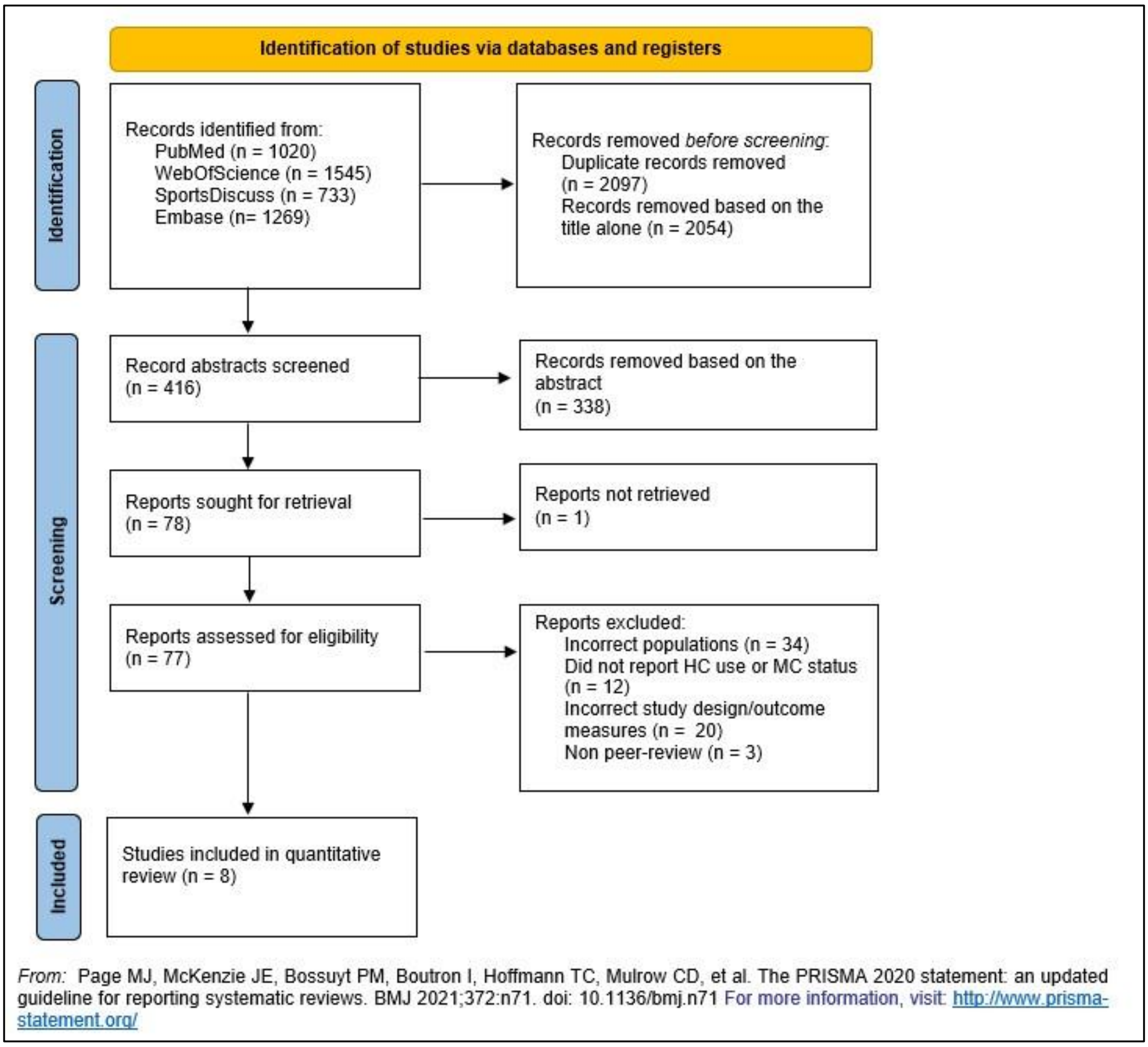

Figure 1. PRISMA flow diagram. Detailed flow of studies examined from the initial search to the final inclusion.

In addition to the database search, the reference lists of all the included studies and relevant review studies found in the search were assessed. Moreover, a backward search using Google Scholar was conducted for all included studies. All duplicate articles were removed. The first two authors (DN and KLN) independently assessed each article identified from the searches by applying the exclusion and inclusion criteria to the titles and abstracts. Each study carried forward from this stage was fully read and reviewed independently by these same authors, aiming to determine the studies to be included in the meta-analysis. Conflicting opinions were resolved via discourse between the first and second authors (DN and KLN), with the last authors (BE & MM) acting as mediators, if necessary. Reasons for exclusion of studies were recorded and are displayed in Figure 1.

2.2. Study Selection

Research publications were considered eligible if the following inclusion criteria were met: 1) all research made available prior to 12 January 2023; 2) were in English and peer-reviewed; 3) were experimental in design; 4) used a resistance exercise training intervention (resistance exercise training was defined as interventions in which the muscles contract against an external resistance with the intent of inducing adaptations resulting in increases in hypertrophy, power, or strength); 5) measured muscular hypertrophy, power, or strength outcomes; 6) at least two data points (pre- and post-measures); 7) included healthy biological female participants with a mean age of ≥18 and ≤ 40 years; 8) used training interventions ≥ 4 weeks in length; and 8) direct comparison of HC users and non-users. The exclusion criteria were as follows: 1) age <18 or > 40 years; 2) individuals with menstrual dysfunction or other comorbidities; 3) concurrent exercise training interventions; 4) used training interventions ≤ 4 weeks in length.

2.3 Data Extraction, Moderators, and Study Quality

The first two authors independently extracted sample sizes, means, and standard deviations (SD) or standard errors (SE) of the outcome measures from each study. Where data were not reported in sufficient detail, or did not allow for appropriate extraction, requests for data were made by contacting the corresponding author. The authors were contacted a maximum of three times with a one-week time interval between contact efforts. If the email address of the author was not working or was not publicly available, the private message function of the Research Gate website was used as the method of contact. In one study [22], statistical information was extracted from study figures using WebPlotDigitizer (Version 4.6, Pacifica, CA, USA). Two studies [15,19] provided data from the same participants and intervention, as confirmed via direct communication with the corresponding author. Thus, the extracted data were considered to be from one study for the purpose of analysis. All described techniques were applied when we did not receive missing information from the study authors, as suggested by the Cochrane Handbook [27]. Inter-rater agreement for all extracted data used in the effect size calculation was assessed using an intraclass correlation coefficient (ICC) for continuous data. Any dissimilarities were located and resolved before the final calculations were completed.

In addition to quantitative information, *a priori* moderators were extracted, including characteristics of the experimental interventions (length of intervention, supervision status, mode of resistance training, number of exercises, training frequency, number of sets, intensity, and rep ranges used), participant characteristics (age, height, body mass, and training status), and features of the paper (country, publication year, and research group).

Inter-rater agreement for all coded moderators was assessed as an unweighted Cohen's kappa. Dissimilarities, if any, were located and resolved before the final calculations were completed.

The methodological quality of the included studies was assessed using the "Tool for the assessment of study quality and reporting in exercise" (TESTEX) [28]. TESTEX is a 12-item scale divided into two sections: study quality (Items 1-5) and study reporting (Items 6-12), and represents a modified version of the PEDro scale [29]. The scale was modified for use in this review (see Electronic Supplementary Material Appendix). Items 2, 3, and 10, referring to randomisation of intervention groups, allocation concealment, and activity monitoring in control groups, respectively, were deemed irrelevant to the design of the studies in this current review and were removed. Two additional items (Items 2 and 10 in the modified version) were included: Q2. Were the participants confirmed to be habitual HC users or habitual non-users for at least 3 months prior to the study? Q10. Was the type of HC described to the level of detail required for categorisation or replication? Each question was awarded one point if the criteria were satisfied, with Items 5 and 7 containing three and two questions, respectively. The maximum number of points that could be scored on this modified 11-item checklist was 14.

2.4 Calculation of Effect Sizes

All the outcomes were analysed as in differences between mean change difference (Hedge's *g*) between the HC and non-HC conditions in R (version 4.0.5; R Core Team, 2022) using the escalc function in the metafor package (Viechtbaur, 2010). Standardised mean change for the HC and non-HC conditions were computed using the pre-test standard deviations and a bias correction factor [30]. As the pre–post-test correlations were not available in the studies, an estimate correlation of 0.7 was used to compute the standardised mean changes, while also testing alternative correlations of 0.5 and 0.9. The difference in the standardised mean changes were then computed by subtracting the standardised mean change of the HC condition from the non-HC condition [31]. The corresponding sampling variances were computed by summing the sampling variances of the two conditions.

2.5 Statistical Analysis

A multilevel maximum likelihood random effects model [30] was fitted to the data using R (version 4.0.5; R Core Team, 2022) and the Metafor package (Viechtbauer, 2010). The adopted meta-analytic approach utilised multilevel modelling to account for the non-independence of effect sizes. Specifically, the authors implemented a meta-analytic multilevel model that incorporated a variance-covariance matrix in the model [30]. This approach allowed the authors to account for the fact that the effects sizes were nested within studies, which in turn improved the ability to estimate the true effect size. The models used an estimate of 0.9 for dependence of effects, informed by expert opinion of the authors. As the exact magnitude of dependence of the effects was unknown, robust variance estimator from the clubSandwich package was used to improve the accuracy of the estimates [32].

In the multivariate model, random effects were added for each effect size within each study, allowing the effect sizes to correlate and have different variances. Parameters of *tau2* and *I2* were used to examine the between-study heterogeneity of the effects [33]. Furthermore, as the *Q* statistic for heterogeneity cannot be applied to multilevel models, a likelihood ratio test examining the effect of *tau2* on all outcomes was used as an indicator of significant between-study heterogeneity. The between-study heterogeneity of the effect sizes was indicated if the likelihood ratio test ($\chi 2$) reached a significance level of $p < 0.05$, and the sampling error contributed to the observed variance of less than 75% [34].

The moderators were used in a linear regression analysis as univariate independent variables to explain the possible heterogeneous effects of the outcomes. Interactions of the moderators were not tested because of the lack of statistical significance of the models, low between-study heterogeneity, and inadequate number of effects for certain outcomes (i.e., power) [35]. A modified version of Egger's test [36] using the standard error of the observed outcomes as a predictor in a multivariate model and a visual examination of the contour-enhanced funnel plots were used to detect publication bias. The presence of outliers and influential studies/effects was analysed using Cook's distance and the distribution of studentized residuals [37].

The sensitivity analyses were computed using alternative pre-post correlations in computing the effect sizes as well as examining different autocorrelations in computing the variance-covariance matrix. The results of the sensitivity analysis are listed in Table 2.

The aggregated dataset and R-code used for the analysis can be found on the OSF website (Link). Additional information can be shared on request.

3. Results

In total, 54 effects from 8 studies were derived for hypertrophy (k = 20), power (k = 8), and strength (k = 26) outcomes. The study selection process from the initial search to final inclusion is shown in Figure 1. The total number of participants was 325 (n=159/166; OCP/naturally-menstruating), with a weighted mean age of 24.0 years. All the included studies investigated the influence of OCPs, with no study including participants using other types of HC. The exercise interventions lasted between 8 and 16 weeks, with a mean duration of 11.1 ±2.5 weeks, and a mean number of 3.5 ±0.5 sessions per week. The mean TESTEX scale score was 9.4, with individual studies ranging from 5 to 13. Individual scores for quality assessment can be found in the

Electronic Supplementary Material. The complete descriptive information of the included studies is presented in Table 1.

The interrater agreement statistics support strong agreement between authors. Initially the absolute agreement between the two first authors for all extracted continuous data using the two-way mixed effect model and "single rater" unit for ICC was 0.99 [0.99-0.99], $p < 0.001$. The initial inter-rater reliability for moderator coding was in perfect agreement (unweighted Cohen's Kappa, [2, 330] = 1.00, z = 0, $p < 0.001$, 95% CI = [1.00,1.00]; percent agreement = 100%).

Table 1. Study Characteristics

Study	*n*	Training Status	Intervention Duration (wks)	Outcomes	Resistance Exercise Training Intervention	Study Conclusion
Dalgaard et al., 2019 [20]	OCP -users: 14 Naturally Menstruating: 14	Untrained	10	**Hypertrophy:** MRI: • Vastus Lateralis Muscle CSA Biopsy: • Vastus Lateralis Type I Fibre CSA • Vastus Lateralis Type II Fibre CSA **Strength:** 1RM: • Knee Extension Isokinetic Dynamometer MVIC:	10 weeks of progressive resistance exercise training performed 3 times per week supervised by physical therapists. Training intensities were estimated from the 1 RM test. The exercises consisted of seated knee extensions and inclined leg press performed in a progressive manner; Week 1: 3x 12 repetitions of 15 RM Week 2–3: 3x 12 repetitions of 12 RM Week 4–5: 3x 10 repetitions of 10 RM Weeks 6–10: 4x 10 repetitions of 10 RM.	Use of OCPs was associated with a trend toward a greater increase in muscle mass and a significantly greater increase in type I muscle fibre area compared to controls. Use of OCPs did not influence the overall increase in muscle strength related to training.

				• Knee Extension		
Dalgaard et al., 2022* [19]	OCP -users: 20 Naturally Menstruating: 18	Untrained	10	**Hypertrophy:** DEXA: • Fat-Free Mass MRI: • Vastus Lateralis Muscle CSA (10cm) • Vastus Lateralis Muscle CSA (20cm) • Vastus Lateralis Muscle CSA (30cm) Biopsy: • Vastus Lateralis Type I Fibre CSA	10 weeks of supervised resistance exercise training with 3 sessions per week. Four different resistance-training exercises for the legs were performed: Leg press, leg curl, leg extension, and back extension. In addition, 2 upper body exercises were performed: Lat pull down and incline crunch. The length of one training session was 45 minutes. The exercises were performed in a progressive manner as 3–4 sets of 8–12 repetitions, corresponding to their 8–12 repetition maximum. Participants were encouraged to use maximal effort and train near momentary muscle failure. All training sessions were supervised by an exercise therapist. The lifted loads were monitored using individual training logs to ensure subjects adjusted weights throughout the entire training period to maintain muscle loading as muscle strength increased.	The use of a second generation OCP in young untrained women does not promote significantly greater gains in muscle mass or muscle strength compared with nonusers.

				• Vastus Lateralis Type II Fibre CSA **Power:** • Counter-Movement Jump **Strength:** 1RM: • Leg Press Isokinetic Dynamometer MVIC: • Knee Extension • Knee Flexion		
Nichols et al., 2008 [22]	OCP -users: 13 Naturally Menstruating: 18	Trained (NCAA Division 1 Collegiate Athletes)	12	**Strength:** 1RM: • Bench Press 10RM: • Knee Extension Isokinetic Dynamometer Peak Torque: • Bench Press	12-week preseason strength development program. No attempt was made by the researchers to modify the athletes' existing strength training program as designed by the university's strength and conditioning coach. This program consisted of free weight and machine lifting exercises involving the major muscle groups, performed three times per week. Resistance levels were based on percentages ranging from 50% to 80% of initial 1 repetition maximum tests. Individual training logs were	The use of OCPs did not provide sufficient androgenic effect to increase strength gains beyond the stimulus of the training protocol.

				• Knee Extension	maintained to monitor subjects' numbers of sets, repetitions, resistance levels, and program compliance.	
Oxfeldt et al., 2020* [15]	OCP -users: 20 Naturally Menstruating: 18	Untrained	10	**Hypertrophy:** Biopsy: • Vastus Lateralis Type I Fibre CSA • Vastus Lateralis Type II Fibre CSA	Same as Dalgaard et al., 2022 [19] above.	Use of 2nd generation OCPs in young untrained women increased skeletal muscle MRF4 expression and satellite cell number compared to non-users.
Reichmann and Lee, 2021 [16]	OCP -users: 34 Naturally Menstruating: 38	Untrained	10	**Hypertrophy:** Hydrostatic Weighing: • Lean Mass **Strength:** 1RM: • Arm strength (aggregated score) • Leg strength (aggregated score)	10 weeks of resistance exercise training, performed 3 times a week under the supervision of exercise physiologists. The participants performed 3 sets of 6–10 repetitions for each of the following exercises with the resistance set at 75% of each individual's predetermined maximum strength (chest press, incline press, lat pull-down, seated row, shoulder press, leg extension, hamstring curl, triceps extension, arm curl, back extension, and abdominal crunch. weight machines; leg press and calf raises were performed on a Universal leg press machine. The subjects were instructed to perform as many repetitions as possible on every set until they reached muscle failure or achieved 10 repetitions with correct	OC use impairs muscle gains in young healthy untrained women, but the effect may depend on the type of OCPs.

					forms and full range of motion. For every participant, resistance settings were increased when a subject was able to complete 10 repetitions on a particular set. Resistance was adjusted as needed throughout the study according to the results of biweekly reviews of each subject's progression. The resting time was 30 seconds between sets and one minute between exercises.	
Romance et al., 2019 [23]	OCP -users: 12 Naturally Menstruating: 11	Trained *(> 2 years continuous resistance exercise training)*	8	**Hypertrophy:** DEXA: • Fat Free Mass **Power:** • Counter-Movement Jump **Strength:** 1RM: • Bench Press • Squat	3-week familiarization period to establish training loads for each exercise, followed by an 8-week intervention period. All subjects performed the same exercises; bench press, barbell row, military press, lat pulldown, incline chest press, biceps curl and triceps pushdown, squat, lunge, leg press, hip thrust, leg extension, lying leg curl and standing calf raise. Subjects completed four training sessions per week. Training sessions were monitored by specialists, adjusting the loads whenever necessary. The lifted loads and perceived exertion in each exercise were monitored by the physical conditioning and strength specialist using a paper tracking form throughout the experiment.	OC use does not impair strength gains nor body composition in resistance-trained young adult women.
Sung et al., 2022 [38]	OCP -users: 34 Naturally Menstruating: 40	Untrained	12	**Hypertrophy:** Ultrasound: • Muscle Thickness (Sum of	12 weeks of submaximal strength training. The initial training value was set to 85% of the maximal isometric strength test, and participants performed 3 sets of 8–12 repetitions on a leg-press machine with 2 min of resting intervals between sets until exhaustion. If any	The effects of RET on muscle strength, muscle thickness, muscle fibre size, and composition were similar in young women irrespective of their OCP use.

Rectus Femoris, Vastus Lateralis & Vastus Intermedius) Biopsy: • Vastus Lateralis Type I Fibre Muscle Thickness • Vastus Lateralis Type II Fibre Muscle Thickness **Strength:** Combined Force & Load Cell IMVC: • Leg Press	participant was able to perform more than 12 repetitions during a set, they increased the resistance by 10 kg (i.e., 85–95% of their maximal strength) to reduce the number of repetitions to 12 or less. Supervised training was performed 3 times a week using the leg-press machine and once a week at home using the participant's own body weight (squats). For the latter exercise, participants performed 3 sets of 15–20 leg squats with 3–5 min of recovery between sets.

Wikstrom-frisen et al., 2017 [39]	**Group 1:** OCP -users: 11 Naturally Menstruating: 8 **Group 2:** OCP -users: 10 Naturally Menstruating: 9 **Group 3:** OCP -users: 11 Naturally Menstruating: 10	Trained *(Mean resistance exercise training experience of 3.5 years)*	16	**Hypertrophy:** DEXA: • Leg Lean Mass • Whole Body Lean Mass **Power:** • Counter Movement Jump • Squat Jump **Strength:** Isokinetic Dynamometer Peak Torque: • Single Leg Knee Extension (Right & Left) • Single Leg Knee Flexion (Right & Left)	In this study of four menstrual/OCP cycles, periodised resistance training refers to high frequency leg training during two weeks of the menstrual cycle. The remaining two weeks of respective cycle the women performed the leg resistance training once a week as part of the training program. In group 1 periodised high frequency training was performed (5 times per week) during the first two weeks of the menstrual cycle. In group 2 periodised high frequency training was performed (5 times per week) during the last two weeks of the menstrual cycle. The women in group 3 trained regularly (3 times per week) during the whole menstrual/OCP cycle. The resistance training in the present study consisted of two exercises, leg press and leg curls, and were started at an individual load. The participants performed double leg press and leg curls three sets of 8-12 repetition maximum (RM) with 1-2 minutes of rest between sets and with 2-10 % increase in load applied when the individual performed the current workload for one or two repetitions over the desired number, according to recommendations to achieve strength gains.6, 7 The women also continued their ordinary training with the exception of leg exercises, which were exchanged to the exercise	High frequency periodised leg resistance training during the first two weeks of the menstrual/OCP cycle was more beneficial in terms of power gain, strength gain and increased leg lean mass compared to high frequency resistance training during the last two weeks.

provided by the researchers. Throughout the study a gym instructor was available to guide the training.

*CSA, cross-sectional area; DEXA, dual-energy X-ray absorptiometry; IMVC, isometric maximal voluntary contraction; RM, repetition maximum. *Shared participants.*

Table 2. Sensitivity Analysis

	Hypertrophy Outcomes						Power Outcomes						Strength Outcomes					
Sensitivity Analysis Procedure	**ES**	**95% CI**	$\tau^2_{within-studies}$	$\tau^2_{between-studies}$	$I^2_{within-sttdies}$	$I^2_{between-sttdies}$	**ES**	**95% CI**	$\tau^2_{within-studies}$	$\tau^2_{between-studies}$	$I^2_{within-sttdies}$	$I^2_{between-sttdies}$	**ES**	**95% CI**	$\tau^2_{within-studies}$	$\tau^2_{between-studies}$	$I^2_{within-sttdies}$	$I^2_{between-sttdies}$
0.7 Pre-Post Correlation & 0.9 Correlation Matrix	0.01	[-0.11, 0.13]	0.09	0.00	52.28	0.00	-0.04	[-0.93, 0.84]	0.04	0.00	21.30	0.00	0.10	[-0.08, 0.28]	0.03	0.00	18.77	0.00
0.7 Pre-Post Correlation & 0.7 Correlation Matrix	0.01	[-0.12, 0.13]	0.07	0.00	44.15	0.00	-0.04	[-0.91, 0.83]	0.01	0.00	4.51	0.00	0.09	[-0.10, 0.28]	0.01	0.00	5.49	0.00
0.7 Pre-Post Correlation & 0.5 Correlation Matrix	0.01	[-0.13, 0.14]	0.05	0.00	36.40	0.00	-0.04	[-0.92, 0.83]	0.01	0.00	4.51	0.00	0.09	[-0.10, 0.28]	0.01	0.00	5.49	0.00
0.5 Pre-Post Correlation & 0.9 Correlation Matrix	0.00	[-0.12, 0.11]	0.09	0.00	40.66	0.00	-0.06	[-0.96 0.83]	0.03	0.00	12.18	0.00	0.09	[-0.10, 0.29]	0.02	0.00	11.45	0.00
0.5 Pre-Post Correlation & 0.7	0.00	[-0.13, 0.12]	0.06	0.00	30.75	0.00	-0.06	[-0.96, 0.84]	0.00	0.00	0.00	0.00	0.07	[-0.14, 0.28]	0.00	0.00	0.00	0.00

Correlation Matrix																		
0.5 Pre-Post Correlation & 0.5 Correlation Matrix	0.00	[-0.13, 0.13]	0.04	0.00	22.09	0.00	-0.06	[-0.96, 0.84]	0.00	0.00	6.46	3.24	0.07	[-0.14, 0.28]	0.00	0.00	0.00	0.00
0.9 Pre-Post Correlation & 0.9 Correlation Matrix	0.02	[-0.11, 0.15]	0.09	0.00	72.20	0.00	-0.02	[-0.90, 0.87]	0.04	0.00	43.80	0.00	0.11	[-0.06, 0.27]	0.04	0.00	37.56	0.00
0.9 Pre-Post Correlation & 0.7 Correlation Matrix	0.02	[-0.11, 0.15]	0.07	0.00	68.02	0.00	-0.02	[-0.88, 0.84]	0.03	0.00	33.66	2.91	0.10	[-0.07, 0.28]	0.25	0.00	29.66	0.00
0.9 Pre-Post Correlation & 0.5 Correlation Matrix	0.02	[-0.11, 0.16]	0.06	0.00	63.45	0.00	-0.03	[-0.84, 0.79]	0.01	0.01	19.82	9.93	0.10	[-0.08, 0.28]	0.02	0.00	21.11	0.00

Table 3. OCP Types and Menstrual Status Descriptions

Study **&** ***Length of OCP Use***	**OCP Type**	**OCP Brand Name**	**OCP Dosage**	**Non-user Criteria**
Dalgaard et al., 2019 ***(Mean length of OCP use = 6.1 ±5.0 years)***	3rd Generation Combined Monophasic (n= 7)	Lindynette	75 µg gestodene and 30 µg ethinyl oestradiol	n = 14; Had regular menstrual cycles (self-report) for at least 1 year (within the range of 24–35 days).
	3rd Generation Combined Monophasic (n = 5)	Gestonette	75 µg gestodene and 20 µg ethinyl oestradiol	
	3rd Generation Combined Monophasic (n=2)	Novynette	150 µg desogestrel and 20 µg ethinyl oestradiol	
Dalgaard et al., 2022* ***(Mean length of OCP use = 6.5 ±2.5 years)***	2nd Generation Combined Monophasic (n = 17)	Femicept	150 µg levonorgestrel and 30 µg ethinyl oestradiol	n = 18; Had not been using any form of hormonal contraceptive for the past 3 months and reported to that they had experienced a regular menstrual cycle (menses every 24–35 days) at last 3 months or more before the intervention.
	2nd Generation Combined Monophasic (n = 3)	Cilest	250 µg norgestimate and 35 µg ethinyl oestradiol	
Nichols et al., 2008 ***NR***	2nd Generation Combined (n = 13)	NR	NR	n = 18; Had regular menstrual cycles (menses every 25–35 days).
Oxfeldt et al., 2020* ***(Mean length of OCP use = 6.5 ±2.5 years)***	2nd Generation Combined Monophasic (n = 17)	Femicept	150 µg levonorgestrel and 30 µg ethinyl oestradiol	n = 18; Had not been using any form of hormonal contraceptive for the past 3 months and reported to that they had experienced a regular menstrual cycle (menses every 24–35 days) at last 3 months or more before the intervention.
	2nd Generation Combined Monophasic (n = 3)	Cilest	250 µg norgestimate and 35 µg ethinyl oestradiol	
Reichman and Lee, 2021 ***NR***	Oral contraceptives (n = 34)	Orthotricycle, Orthonovum, Orthocept, Desogen, Nordette, Alesse, Tivora, Estrostep, Loestrin	NR	n = 38; No information was available on the menstrual status of non-OCP users.
Romance et al., 2019	2nd Generation (n=4)	NR	150 µg levonorgestrel and 30 µg ethinyl oestradiol	n = 11; Had reported to have regular menstrual cycles (i.e., occurring on a 28- to 30-day cycle) and

NR	3rd Generation (n=8)	NR	50 µg gestodene and 30 µg ethinyl oestradiol	had not taken any form of synthetic oestrogen or progesterone for at least six months prior to the study.
Sung et al., 2022 ***(OCP use of ≥ 1 year prior to study)***	2nd Generation Combined Monophasic (n= 3)	Anastrella 28	150 µg levonorgestrel and 30 µg ethinyl oestradiol	n = 40; Had no OCP use or hormonal treatment in the past year. Two months of monitoring daily body temperature were performed to establish regularity of menstrual cycle prior to beginning intervention. Mean menstrual cycle length throughout intervention = 28.2 ±1.2 days.
	2nd Generation Combined Monophasic (n=10)	Cilest	250 µg norgestimate and 35 µg ethinyl oestradiol	
	2nd Generation Combined Monophasic (n=8)	Femicept	150 µg levonorgestrel and 30 µg ethinyl oestradiol	
	2nd Generation Combined Monophasic (n= 9)	Loette	100 µg levonorgestrel and 20 µg ethinyl oestradiol	
	2nd Generation Combined Monophasic (n=4)	Microstad	150 µg levonorgestrel and 30 µg ethinyl oestradiol	
Wikstrom-Frisen et al., 2017 ***NR***	Combined Monophasic (n = 11)	NR	NR	n = 44; Had a regular menstrual cycle of 28 days (acceptable 21-35 days).
	Combined Triphasic (n = 20)	NR	NR	

**Shared participants. NR = not reported*

3.1. Hypertrophy Outcomes

For hypertrophy outcomes, 65% of the outcome estimates were positive (favouring the OCP condition), ranging from −0.39 to 1.25. The multivariate model indicated that the standardised mean change difference between the conditions was 0.01 (CI 95% [-0.11, 0.13], t = *0.14*, *p* = 0.90). The standardised mean change difference did not differ significantly from zero and showed no evidence of between study heterogeneity ($\chi^2(1) = 0.00$, $p = 1.00$, $\tau^2_{between\text{-}studies} = 0.00$, $\tau^2_{within\text{-}studies} = 0.09$, $I^2_{between\text{-}studies} = 0\%$,, $I^2_{within\text{-}studies} = 52.3\%$).

The effect sizes aggregated at the study level (one effect per study displayed per outcome) and their CIs, as well as the standardised mean change difference according to a meta-analytic multivariate model and two-level random effects model, are displayed in Figure 2. Influential studies and outlier analyses are shown in Supplementary Figures 2 and 3, respectively.

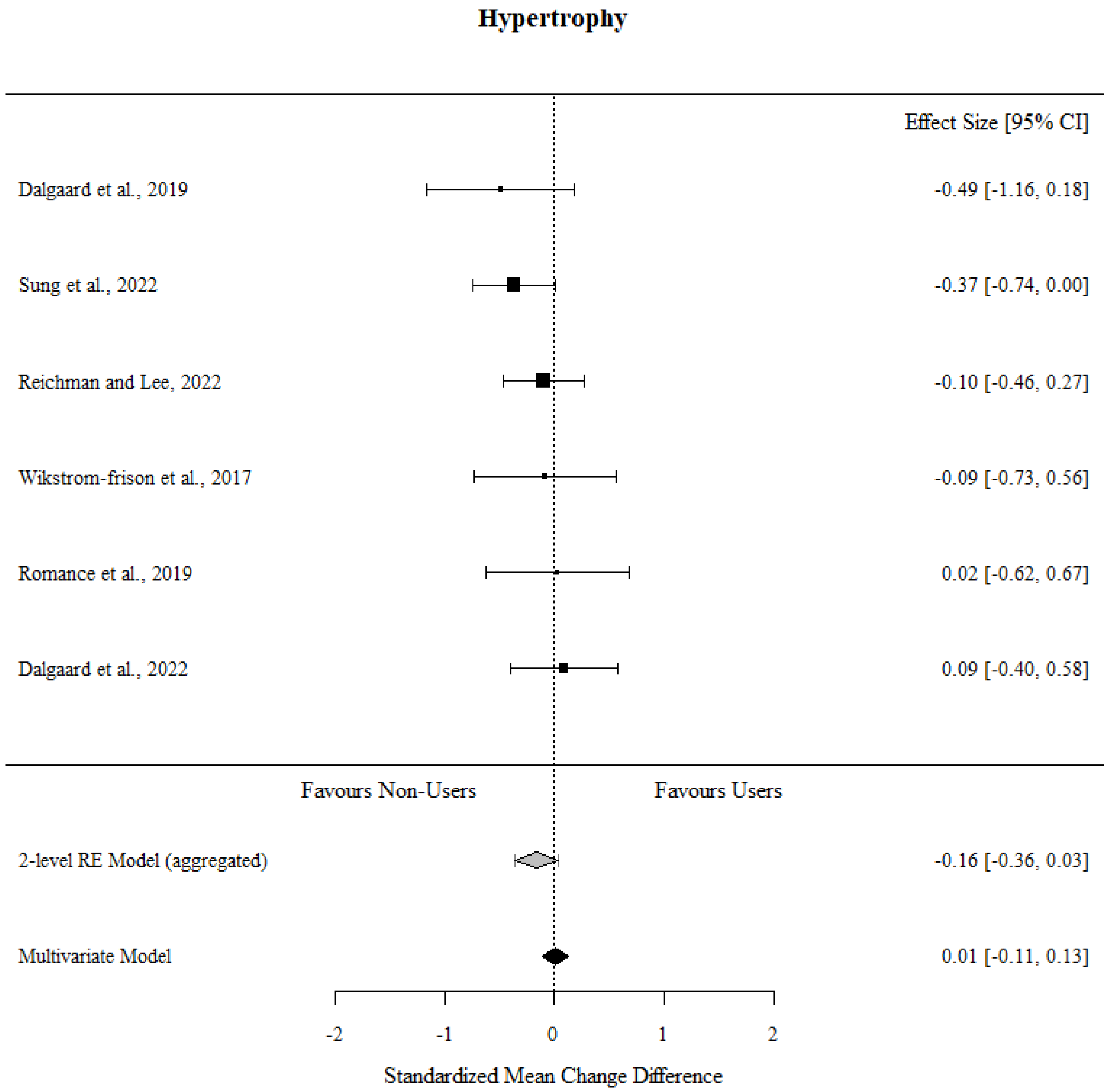

Figure 2. Forest plot of hypertrophy outcomes

3.2. Power Outcomes

For power outcomes, 37.5% of the outcome estimates were positive (favouring the OCP condition), ranging from −0.47 to 0.38. The multivariate model indicated that the standardised mean change difference between the conditions was -0.04 (CI 95% [-0.93, 0.84], t =*-0.29*, *p* = 0.80). The standardised mean change difference did not differ significantly from zero and there was no between-study heterogeneity ($\chi^2(1) = 0.00$, $p = 1.00$, $\tau^2_{between\text{-}studies} = 0.00$, $\tau^2_{within\text{-}studies} = 0.04$, $I^2_{between\text{-}studies} = 0\%$,, $I^2_{within\text{-}studies} = 21.3\%$). The effect sizes aggregated at the study level (one effect per study displayed per outcome) and their CIs, as well as the standardised mean change difference according to a meta-analytic multivariate model and two-level random effects model, are displayed in Figure 4. Influential studies and outlier analyses are shown in Supplementary Figures 2 and 3, respectively.

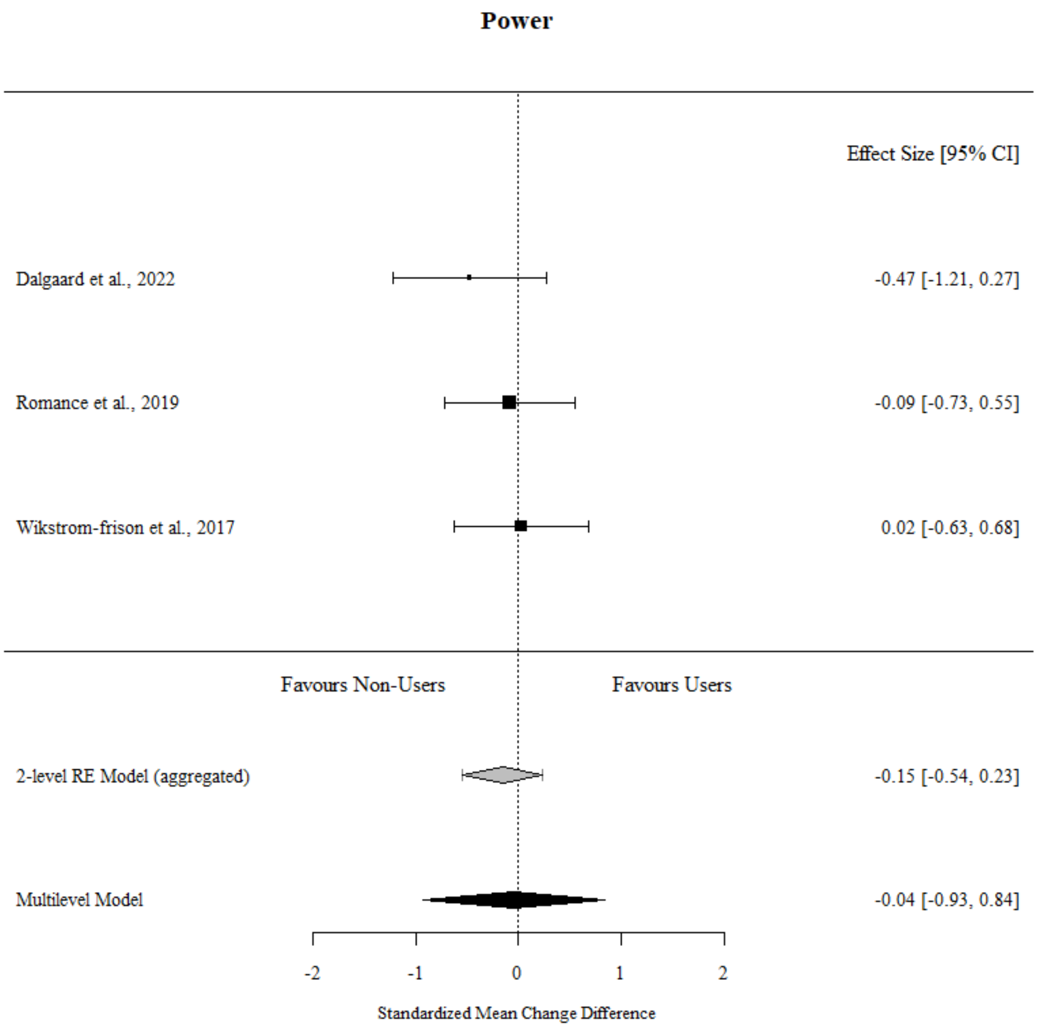

Figure 3. Forest Plot of Power Outcomes

3.3. Strength Outcomes

For strength outcomes, 62% of the outcome estimates were positive (favouring the OCP condition), ranging from −0.35 to 0.62. The multivariate model indicated that the standardised mean change difference between the conditions was 0.10 (CI 95% [-0.08, 0.28], t =*1.48*, p = 0.20). The standardised mean change difference did not differ significantly from zero and showed no between-study heterogeneity ($\chi^2(1) = 0.00$, $p = 1.00$, $\tau^2_{between\text{-}studies} = 0.00$, $\tau^2_{within\text{-}studies} = 0.03$, $I^2_{between\text{-}studies} = 0\%$,, $I^2_{within\text{-}studies} = 18.8\%$). The effect sizes aggregated at the study level (one effect per study displayed per outcome) and their CIs, as well as the standardised mean change difference according to a meta-analytic multivariate model and two-level random effects model, are displayed in Figure 4. Influential studies and outlier analyses are shown in Supplementary Figures 2 and 3, respectively.

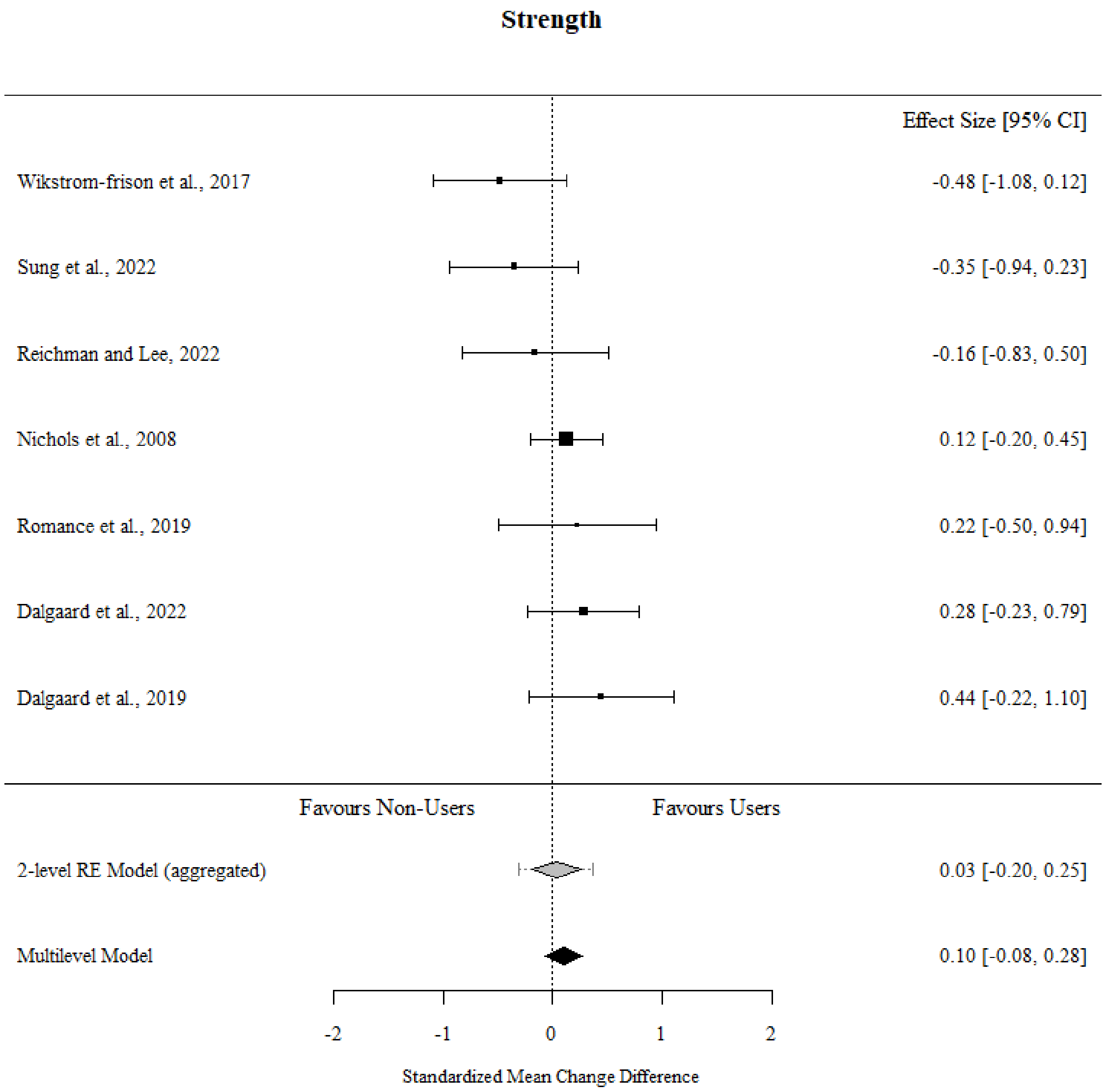

Figure 4. Forest plot of strength outcomes

4. Discussion

This is the first meta-analysis to investigate the influence of HC use on skeletal muscle hypertrophy, power, and strength adaptations in response to resistance exercise training, and found that OCP use had no statistically significant effect on any of these adaptations. Based on the current analysis, there is no evidence-based rationale to advocate for or against the use of OCPs in females partaking in resistance exercise training to increase hypertrophy, power, and/or strength, nor is there evidence that HC use would attenuate these adaptations. Rather, an individualised approach, considering an individual's response to OCPs, and their reason(s) for use may be more appropriate.

There are several suggested mechanisms by which sex hormones may influence adaptations to resistance exercise training. OCPs downregulate the endocrine production of the primary ovarian hormones i.e., oestrogen and progesterone. While oestrogen may influence pathways and processes which influence muscular adaptations to resistance exercise training (i.e., protein turnover, myosin function, and satellite cell activity), its role in the regulation of muscle mass is unclear, and potential mechanisms mediated by progesterone are largely unknown [40]. Oestrogen likely plays a role in modulating protein synthesis/degradation pathways, with differing protein synthesis rates observed in post-menopausal females undergoing oestrogen replacement therapy, compared to those not undergoing hormone replacement therapy [41,42]. Oestrogen may influence muscle strength, via its influence on myosin proteins, as demonstrated by oestrogen deficiency (observed in rodent models and during menopause), negatively impacting the structure-function relation of myosin and actin during activity, reducing force-generating capacity, and increasing fatiguability [43]. Oestrogen may also influence satellite cell activity and function by modulating paired box homeotic gene 7 (a marker of satellite cell number), myogenic differentiation factor D-positive fibres, and DNA uptake of bromo-deoxyuridine, yet this is predominantly shown in ovariectomised rodent models receiving oestrogen replacement [44], and further study in human subjects is warranted. Given the potentially different hormonal profile experienced by OCP users, i.e. downregulated endogenous concentrations of oestrogen and progesterone, an alternative hypothesis is that OCP users may not benefit from theoretical positive benefits of endogenous oestrogen for skeletal muscle adaptations to resistance exercise training. However, the current analysis does not support this hypothesis.

Some methodological considerations that are important to contextualise the findings of this study warrant further discussion. The average study duration was 12.3 weeks, yet increasing lean body mass through targeted interventions is a relatively slow process compared to muscular strength. On average, muscular strength increases by 25% in females following 15-weeks of resistance exercise training, while lean body mass increases by 3.3% (1.4 kg) in the same period [45]. Differences in skeletal muscle hypertrophy, if any, between OCP users and non-users may require a longer time course to manifest than has been studied to date. Studies had relatively small sample sizes (mean n=45; range 28-74), with mean group sizes of 17 across all measures. Larger sample sizes may be warranted in future studies, as the magnitude of response to resistance exercise training varies extensively between individuals for both hypertrophy (-11 to 30%) and strength (-8 to 60%) outcomes [46]. Only three of the studies that met the inclusion criteria reported power outcomes (all lower body), providing only 8 effects, resulting in the meta-analysis model reported likely being underpowered for this outcome measure, evident by the wide confidence interval reported. Therefore, the results of the meta-analysis of the power outcomes should be interpreted with caution. Several studies grouped participants using various brands (differing formulations and dosages), and in some cases, differing generations (differing progestin components). Grouping participants using different types of OCP results in various concentrations of endogenous sex hormones and could result in non-homogenous participant groups [47]. As the potential impact, if any, of HCs on adaptation are likely mediated predominantly by the oestrogenic component, grouping participants using OCPs of differing dosages, androgenicity, or using progestin-only pills is problematic. Genetic variations in tissue-specific oestrogen sensitivity also exist which may confound any potential influence of different contraceptive types [48].

OCPs are used not only to prevent pregnancy, but for multiple reasons, such as in athletes for the alleviation of menstrual-related symptomatology and manipulation of the bleeding phase [49,50]. Negative menstrual cycle symptomology is often reported as a barrier to engaging in exercise training, resulting in reduced training frequency, intensity, and volume [51]. One speculation could be that if OCP use was to reduce the negative menstrual-related symptomatology, resistance exercise training adaptations may be enhanced in these individuals by facilitating completion of higher frequencies, intensities, and volume of training. Based on the current analysis, it must be stressed that at present there is no evidence-based rationale to advocate or oppose the use of OCPs in females participating in resistance exercise training to increase hypertrophy, power, and/or strength.

Future research should consider longitudinal analysis using sufficient sample sizes to account for large variability in exercise response [52], as differences, if any, between HC users and non-users may take considerable time to manifest, particularly for hypertrophy. The presently-available studies investigating the influence of HCs on adaptations to resistance exercise training have exclusively investigated OCPs. Research should also examine the potential influence of different HC types (injection, intrauterine devices, implants, etc.), which result in differing hormonal profiles, on adaptations to resistance exercise training. In future investigations examining the influence of OCPs specifically, appropriate levels of detail describing the type of OCP and providing appropriate biochemical outcomes, such as blood samples, are needed to confirm the hormonal profiles of OCP users and non-users, as previously advocated [12,53]. However, current blood analysis techniques only measure endogenous oestradiol levels, and do not allow for appropriate measurement of exogenous synthetic ethinyl oestradiol [54]. Future research should also ensure intervention groups are appropriately designed to minimise the grouping of OCP users who use different OCP types and dosages, or adequately account for these subgroup differences in their statistical analysis. The impact, if any, of HC and OCPs on power-related adaptations are understudied and warrant further investigation.

5. Conclusion

To the authors knowledge, this is the first systematic review and meta-analysis to conduct a between-group comparison of skeletal muscle hypertrophy, power, and strength adaptations to resistance exercise training in HC users and non-users. This systematic review with meta-analysis showed that OCPs were the only HC studied to date, and OCP use had no statistically significant effect on these adaptations in response to resistance exercise training. As such, these data suggest that OCP use does not positively or negatively influence hypertrophy, power, or strength adaptations in females partaking in resistance exercise training.

6. Statements and Declarations

6.1. Authors' contributions

The study was conceived and designed by DN, KLM, MM, and BE. Data were collected by DN and KLM. Data were analysed by DN and MM. Data interpretation and manuscript preparation were undertaken by DN, KLM, MM, and BE. All authors approved the final written version.

6.2. Funding

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6.3. Competing Interests

The authors have no direct conflicts of interest to declare.

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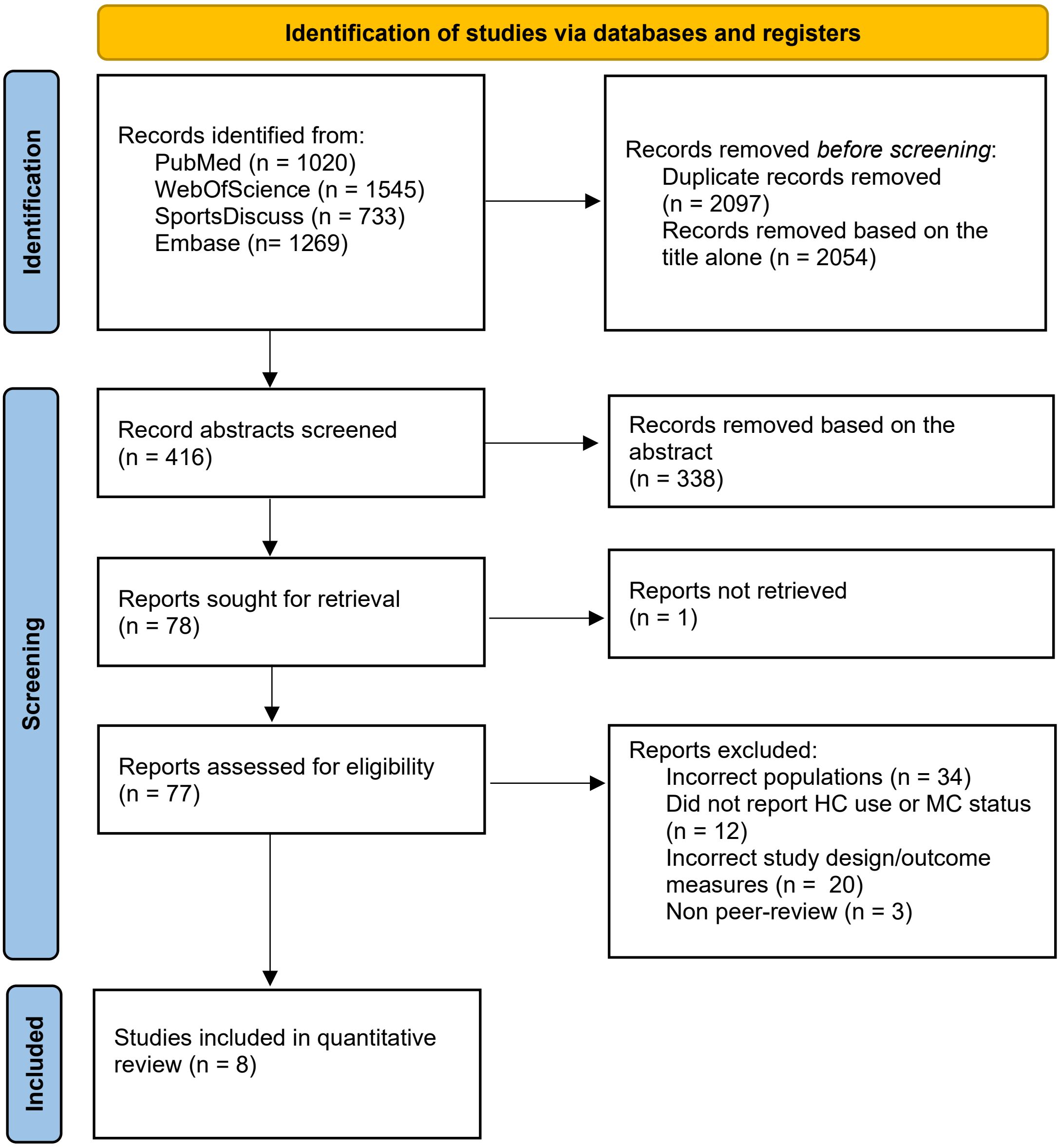
Figure 1

Click here to access/download;Figure;Figure 1. PRISMA Flowchart.pdf



From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71 For more information, visit: http://www.prisma-statement.org/

Figure 2

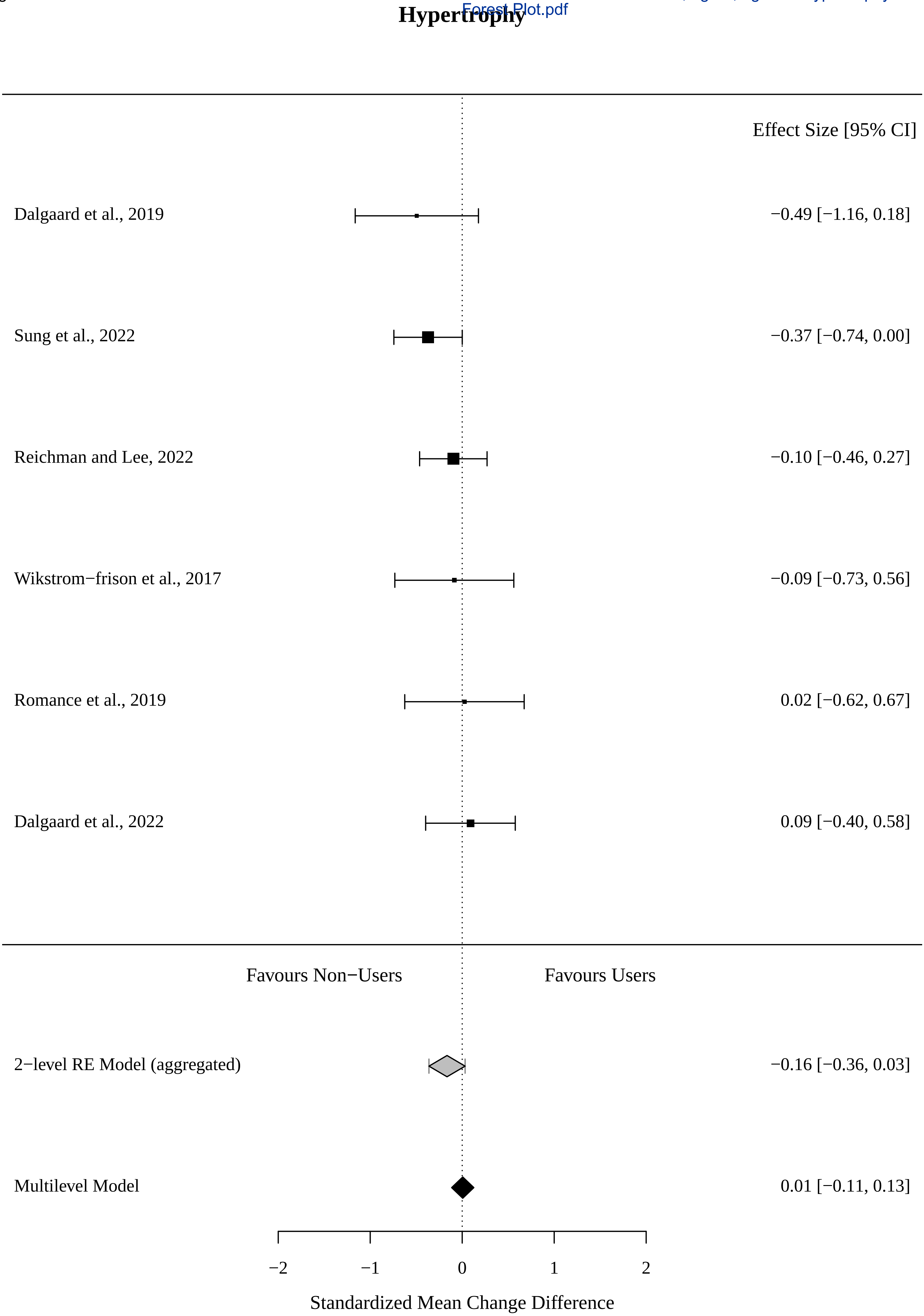

Hypertrophy
Effect Size [95% CI]
Dalgaard et al., 2019
−0.49 [−1.16, 0.18]
Sung et al., 2022
−0.37 [−0.74, 0.00]
Reichman and Lee, 2022
−0.10 [−0.46, 0.27]
Wikstrom−frison et al., 2017
−0.09 [−0.73, 0.56]
Romance et al., 2019
0.02 [−0.62, 0.67]
Dalgaard et al., 2022
0.09 [−0.40, 0.58]
Favours Non−Users
Favours Users
2−level RE Model (aggregated)
−0.16 [−0.36, 0.03]
Multilevel Model
0.01 [−0.11, 0.13]
−2
−1
0
1
2
Standardized Mean Change Difference

Figure 3

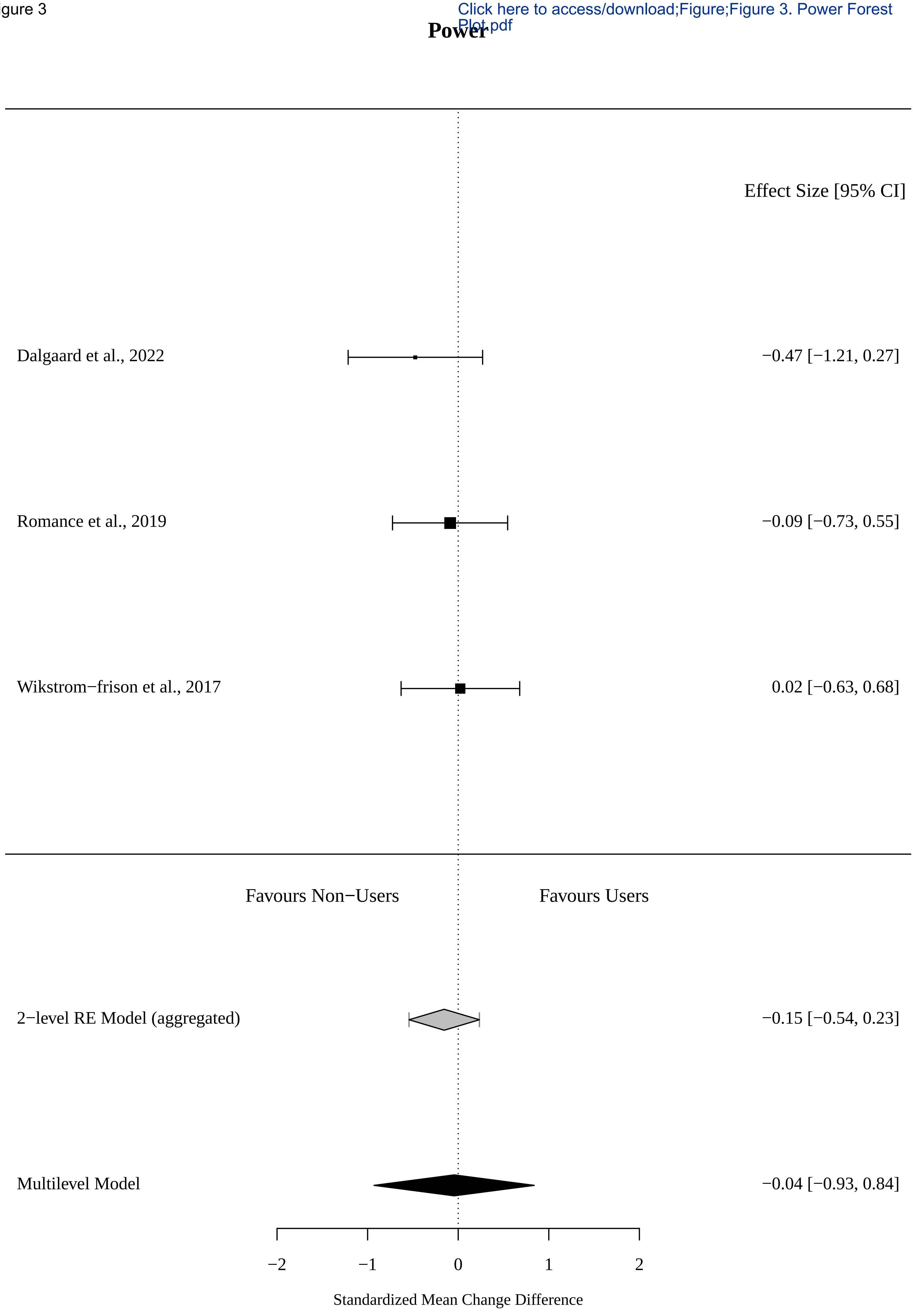
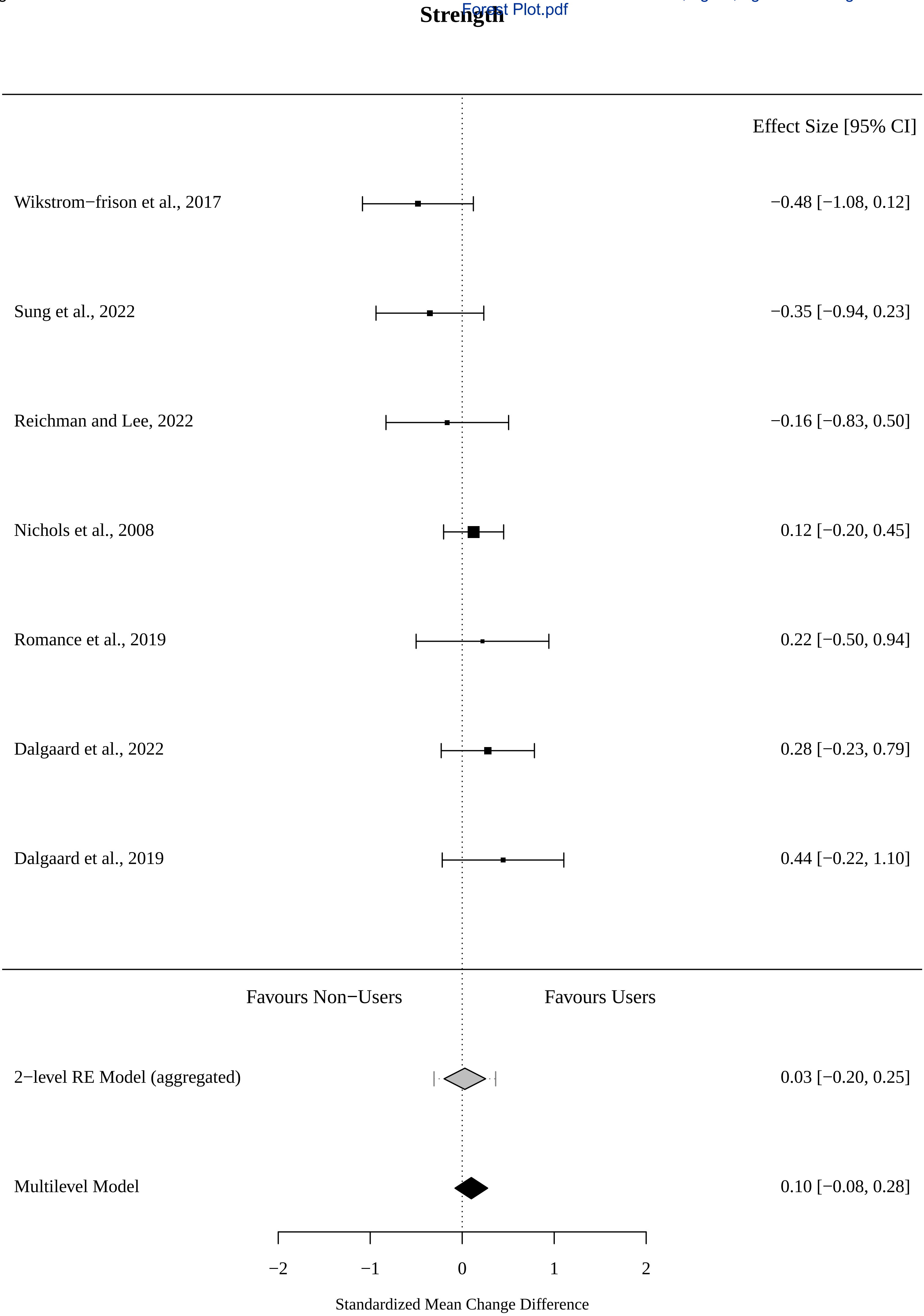

Power
Effect Size [95% CI]
Dalgaard et al., 2022
−0.47 [−1.21, 0.27]
Romance et al., 2019
−0.09 [−0.73, 0.55]
Wikstrom−frison et al., 2017
0.02 [−0.63, 0.68]
Favours Non−Users
Favours Users
2−level RE Model (aggregated)
−0.15 [−0.54, 0.23]
Multilevel Model
−0.04 [−0.93, 0.84]
−2
−1
0
1
2
Standardized Mean Change Difference

Figure 4


Strength
Effect Size [95% CI]
Wikstrom−frison et al., 2017
−0.48 [−1.08, 0.12]
Sung et al., 2022
−0.35 [−0.94, 0.23]
Reichman and Lee, 2022
−0.16 [−0.83, 0.50]
Nichols et al., 2008
0.12 [−0.20, 0.45]
Romance et al., 2019
0.22 [−0.50, 0.94]
Dalgaard et al., 2022
0.28 [−0.23, 0.79]
Dalgaard et al., 2019
0.44 [−0.22, 1.10]
Favours Non−Users
Favours Users
2−level RE Model (aggregated)
0.03 [−0.20, 0.25]
Multilevel Model
0.10 [−0.08, 0.28]
−2
−1
0
1
2
Standardized Mean Change Difference

TITLE

The effect of hormonal contraceptive use on skeletal muscle hypertrophy, power, and strength adaptations to resistance exercise training: a systematic review and multilevel meta-analysis

RUNNING TITLE

Hormonal contraceptives and resistance exercise training

JOURNAL

Sports Medicine

AUTHORS

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The effect of hormonal contraceptive use on skeletal muscle hypertrophy, power, and strength adaptations to resistance exercise training: a systematic review and multilevel meta-analysis. Sports Medicine. Corresponding author: Dr. Brendan Egan, School of Health and Human Performance, Dublin City University, Dublin, Ireland. Email: Brendan.egan@dcu.ie

Electronic Supplementary Material

Electronic Supplementary Material Table 1. PRISMA Checklist

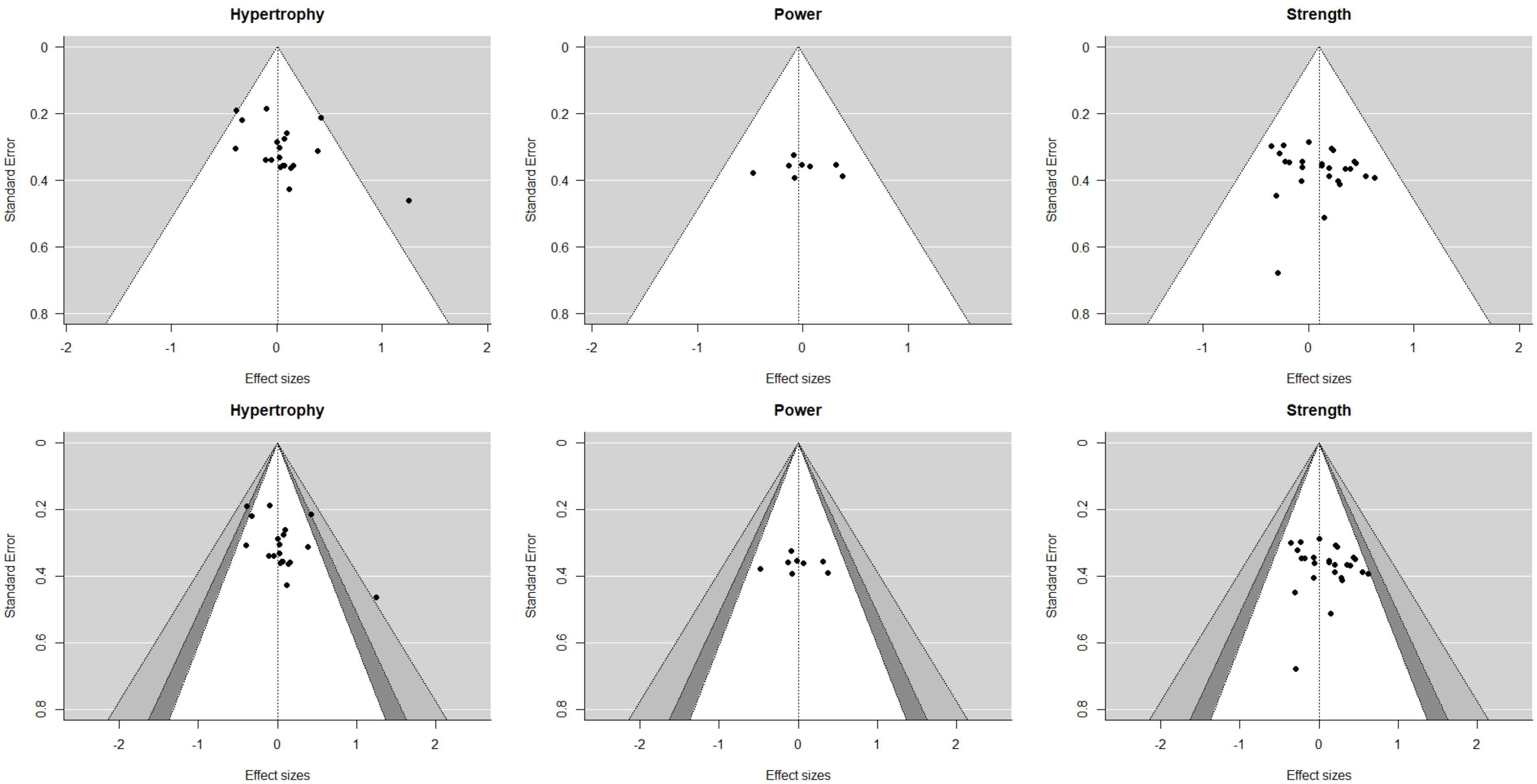
Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	3-4
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	4
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	6-7
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	4
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	4
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	5
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	6-7
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	6
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	6

Section and Topic	Item #	Checklist item	Location where item is reported
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	8
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	7
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	6-7
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	6-7
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	8-9
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	7-8
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	8
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	7-8
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	8
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	7-8
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	5
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	N/A
Study characteristics	17	Cite each included study and present its characteristics.	10-17
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Electronic Supplementary Materials
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	22-24
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	22-24
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	22-24
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	22-24

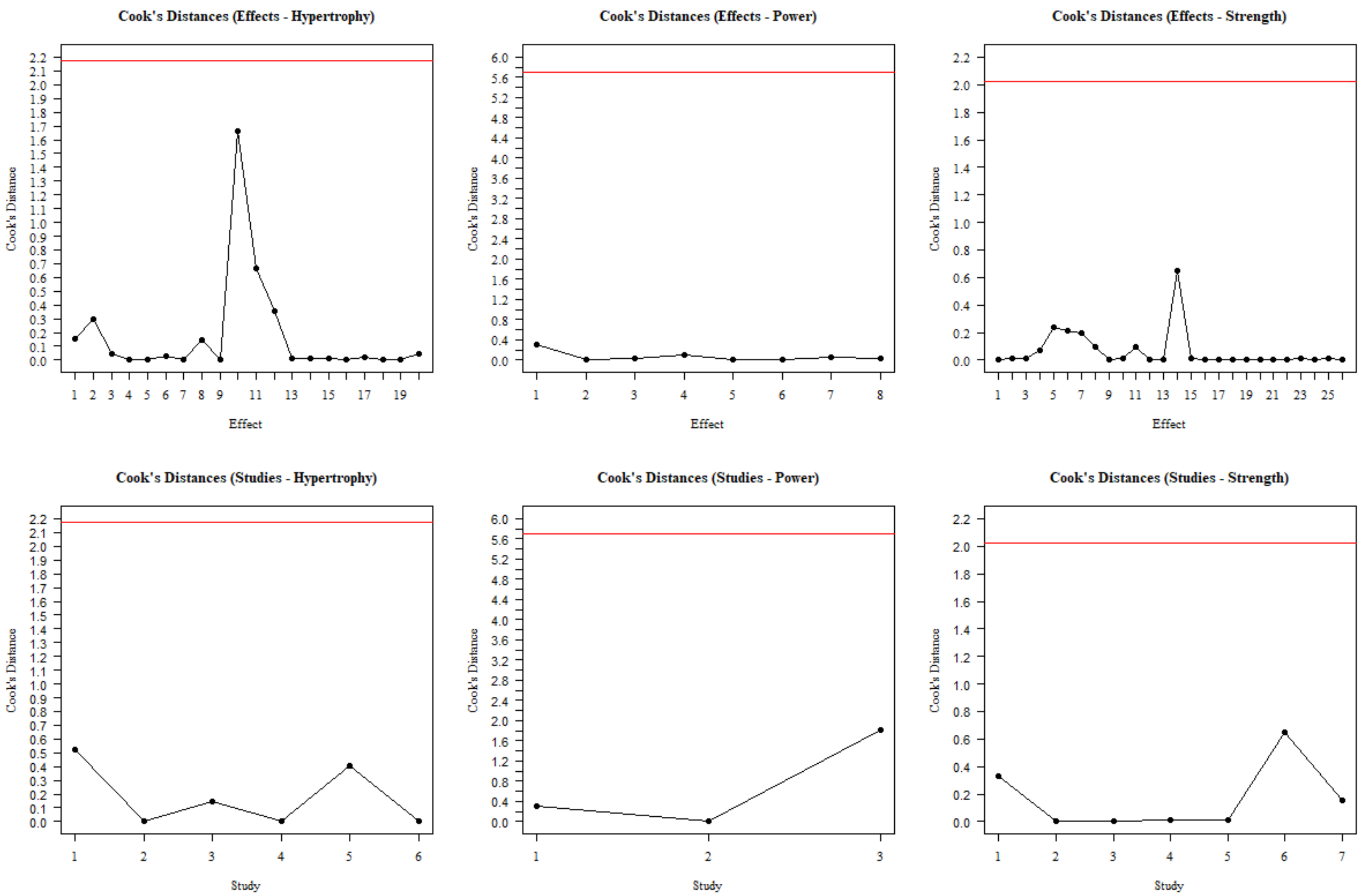
Section and Topic	Item #	Checklist item	Location where item is reported
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	18
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Electronic Supplementary Materials
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	22-24
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	25
	23b	Discuss any limitations of the evidence included in the review.	25-26
	23c	Discuss any limitations of the review processes used.	26
	23d	Discuss implications of the results for practice, policy, and future research.	26-27
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	4
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	4
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	4
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	27
Competing interests	26	Declare any competing interests of review authors.	27
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	8

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

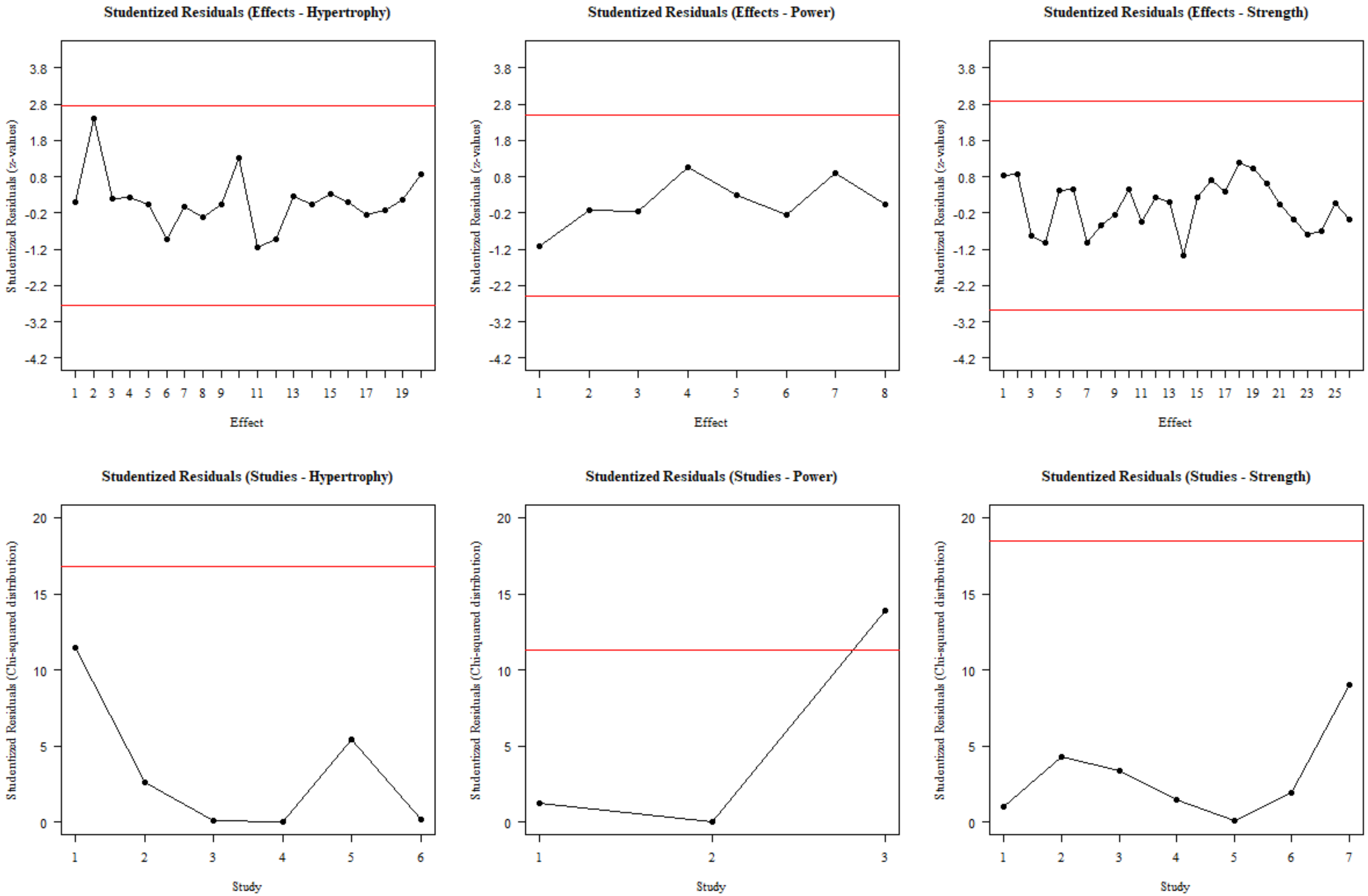
For more information, visit: http://www.prisma-statement.org/



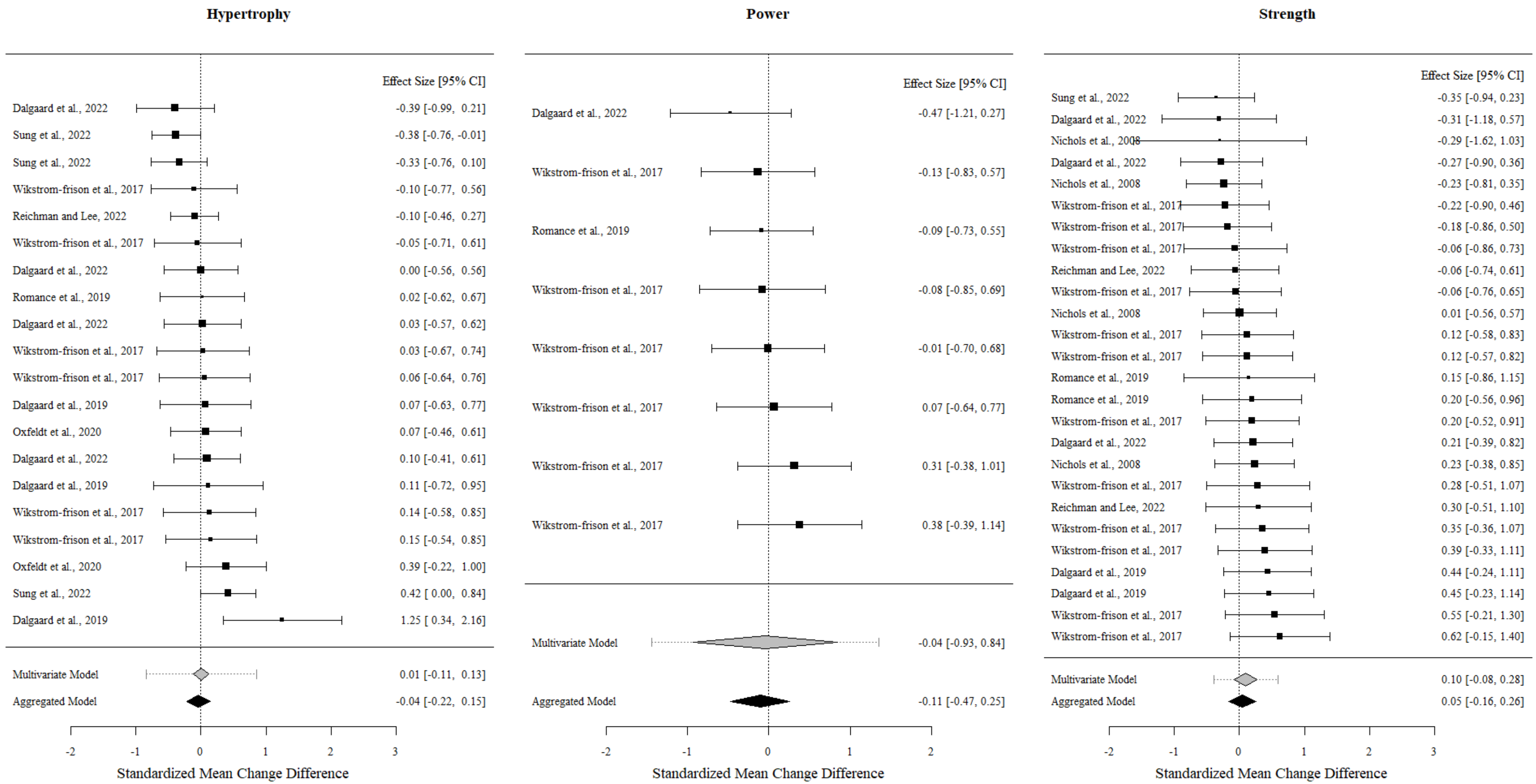
Electronic Supplementary Material Figure 1 - Funnel Plots



Electronic Supplementary Material Figure 2. Influential Effects and Studies Analysis



Electronic Supplementary Material Figure 3. Outlier Analysis



Electronic Supplementary Material Figure 4. Forest Plots Displaying Individual Outcome Effects

Electronic Supplementary Material Table 2. TESTEX Quality Appraisal of Included Studies.

Study	Item 1.	Item 2.	Item 3.	Item 4.	Item 5a.	Item 5b.	Item 5c.	Item 6.	Item 7a.	Item 7b.	Item 8.	Item 9.	Item 10.	Item 11.	Total Score
Dalgaard et al., 2019	1	1	1	1	1	0	1	0	1	1	1	1	1	1	**12**
Dalgaard et al., 2022	1	1	1	1	1	1	1	0	1	1	1	1	1	1	**13**
Nichols et al., 2008	1	1	0	1	0	0	0	0	1	1	0	0	0	1	**6**
Oxfeldt et al., 2020	1	1	1	1	1	1	1	0	1	1	1	1	1	1	**13**
Reichmann and Lee, 2021	1	0	1	0	0	0	0	1	1	1	1	1	1	1	**9**
Romance et al., 2019	1	1	1	0	0	0	0	0	1	1	1	1	1	1	**9**
Sung et al., 2022	1	1	0	0	0	0	0	0	1	1	1	1	1	1	**8**
Wikstrom-Frisen et al., 2017	1	0	1	0	0	0	0	0	1	1	1	0	0	0	**5**

Item	Criteria
1	Eligibility criteria specified.
2	Groups defined and confirmed.
3	Groups similar at baseline.
4	Blinding of assessor (for at least one key outcome).
5a	Study withdrawals reported.
5b	Adverse events reported.
5c	Session attendance report.
6	Intention-to-treat analysis.
7a	Primary outcome reported.
7b	Secondary outcome(s) reported.
8	Point measures and measures of variability for all reported outcome measures.
9	The type of hormonal contraceptive was described to the level of detail required for categorisation or replication.
10	Relative exercise intensity remained constant.

11	Exercise volume and energy expenditure.

Appendix E: Ethical approval forms

Ollscoil Chathair Bhaile Átha Cliath
Dublin City University

DCU

Dr. Brendan Egan
School of Health and Human Performance

Mr. David Nolan
School of Health and Human Performance

7th October 2020

REC Reference: **DCUREC/2020/198**

Proposal Title: **Period Prevalence and Perceived Side Effects of Hormonal Contraceptive Use and the Menstrual Cycle in Athletes**

Applicant(s): **Dr. Brendan Egan and Mr. David Nolan**

Dear Colleagues,

This research proposal qualifies under our Notification Procedure, as a low risk social research project. Therefore, the DCU Research Ethics Committee approves this project.

Materials used to recruit participants should state that ethical approval for this project has been obtained from the Dublin City University Research Ethics Committee.

Should substantial modifications to the research protocol be required at a later stage, a further amendment submission should be made to the REC.

Yours sincerely,

Geraldine Scanlon

Dr Geraldine Scanlon
Chairperson
DCU Research Ethics Committee

DCU Research & Innovation

Taighde & Nuálaíocht Tacaíocht
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Dublin City University

DCU

Mr. David Nolan
School of Health and Human Performance

Dr. Brendan Egan
School of Health and Human Performance

26th January 2021

REC Reference:	**DCUREC/2020/283**
Proposal Title:	**Attitudes of elite level rugby coaches towards sex-related differences in training response and performance: a thematic analysis**
Applicant(s):	**Mr. David Nolan and Dr. Brendan Egan**

Dear Colleagues,

Further to expedited review, the DCU Research Ethics Committee approves this research proposal.

Materials used to recruit participants should note that ethical approval for this project has been obtained from the Dublin City University Research Ethics Committee.

Should substantial modifications to the research protocol be required at a later stage, a further amendment submission should be made to the REC.

Yours sincerely,

Geraldine Scanlon

Dr Geraldine Scanlon
Chairperson
DCU Research Ethics Committee

DCU
Research & Innovation

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DCU

Dr. Brendan Egan
School of Health and Human Performance

Mr. David Nolan
School of Health and Human Performance

17th May 2022

REC Reference: **DCUREC/2022/012**

Proposal Title: **An analysis of the game demands of women's international rugby union**

Applicant(s): **Dr. Brendan Egan, Mr. David Nolan, and Ms. Orlaith Curran**

Dear Colleagues,

Thank you for your application to DCU Research Ethics Committee (REC). Further to expedited review, DCU REC is pleased to issue approval for this research proposal.

DCU REC's consideration of all ethics applications is dependent upon the information supplied by the researcher. This information is expected to be truthful and accurate. Researchers are responsible for ensuring that their research is carried out in accordance with the information provided in their ethics application.

Materials used to recruit participants should note that ethical approval for this project has been obtained from the Dublin City University Research Ethics Committee. Should substantial modifications to the research protocol be required at a later stage, a further amendment submission should be made to the REC.

Yours sincerely,

Dr Melrona Kirrane

Dr. Melrona Kirrane
Chairperson
DCU Research Ethics Committee

DCU
Research & Innovation

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IRFU

IRFU Research Committee

24th November 2021

REF: 21-21

Dear David,

Many thanks for your application to the IRFU Research Committee in relation to the research project entitled: **An analysis of the game demands of women's international rugby union.**

Your application was evaluated by the IRFU Research Committee and it has been approved subject to minor clarifications. Please see below for specific comments.

Recommendation: Approved subject to minor clarification (see below)
Specific comments of the reviewers requiring attention: 1. Proof of ethical approval

Can you kindly forward a copy of the ethical approval once you have received it, to the Research Committee (caithriona.yeomans@irfu.ie) for our records.

If you require any further assistance while carrying out your proposed research or have any queries, please contact Dr Caithríona Yeomans.

With kind regards,

Prof Giles Warrington PhD, FACSM

Chair, IRFU Research Committee
Head of Department, Physical Education and Sport Sciences (PESS)
University of Limerick
Phone: +353 (0)61 234903 Email: giles.warrington@ul.ie

Appendix F: Interview guide used in thematic analysis studies

Question	Probes	Stimuli	Purpose
1. Do you believe that females respond differently to resistance training compared to males? How and Why?	• What evidence or resources are you forming this opinion from? • Please explain how you have seen this in practice, examples?	• Quality of evidence? • Attitudes changed with experience and why?	Explores the opinion on sex-related differences in adaptation to resistance training.
2. What is your perspective on prescribing training and delivering S&C differently for male and female athletes?	• Can you please give a detailed example of this in practice? • Do you prescribe training differently? Can you give examples? • Why do you prescribe training differently? • What results have you observed with this approach? • Have you seen any differences in injury rates or profiles between male and female athletes? Could you provide examples?	• Work capacity? • Recovery? • Injury profile? • Maturation? • Practices changed with experience and why?	Exploring differences in practice towards resisting training between male and female athletes.
3. Can you tell me what influence you believe the menstrual cycle has on performance, if any at all?	• Do you speak about the menstrual cycle with your athletes and why? If so, what do you speak about? • Could you please explain your understanding of what is happening physiologically at the different stages of the menstrual cycle and how it may impact performance? • How do you monitor the	• Culture and environmental influences? • Relationship with athletes? • Attitudes of management? • Scope of practice?	Explore the understanding of the menstrual cycle, it's potential impact on performance and coaches monitoring practices.

	menstrual cycle with your athletes, if at all? What do you monitor? • What "red flags" or warning signs would you be aware of in regards to menstrual function? • Do you notice any differences, physically, psychologically or emotionally in your athletes across the menstrual cycle? • Do your athletes ever approach you to discuss their menstrual cycle or side-effects they are having? If so, what do they say? • How do these conversations influence your practice? Does it influence decision making and planning of training?		
4. Can you tell me what influence you believe hormonal contraceptives have on performance, if any at all?	• Do you speak about hormonal contraceptives with your athletes and why? • If so, what do you speak about? • Could you please explain your understanding of what is happening physiologically when using hormonal contraceptives?	• Culture and environmental influences? • Relationship with athletes? • Attitudes of management? • Scope of practice?	Explore the understanding of hormonal contraceptives, it's potential impact on performance and coaches monitoring practices.

5. What do you believe are the “unknowns” in the difference between males and females with regards to physical preparation?	• What key questions do you have as a coach when it comes to the female athlete? • What significance do you believe research would have exploring these questions? • How would having the answers to these questions influence your practice?	• Scientific literacy? • Sources of educational resources?	What research questions would practitioners like to be explored?
6. Do you think coaches know enough about sex-related differences in strength and conditioning, and preparing the female athlete?	• Do you believe coaches could benefit from improved education in this area? • Is education in this area a feature of your sport or system? • What form should the education take? • What are the areas you feel the education should focus on? • Where do you look to for upskilling or educating yourself in this domain? What resources do you use? Where do you access this information?	• Culture and environment? • Organisational attitudes? • Existing opportunities?	To establish whether coaches value education in this topic area and their preferences in it’s delivery.

Appendix G: Survey – Period Prevalence and Perceived Side Effects of Hormonal Contraceptive Use and the Menstrual Cycle in Athletes

Period Prevalence and Perceived Side Effects of Hormonal Contraceptive Use and the Menstrual Cycle in Athletes

Period Prevalence and Perceived Side Effects of Hormonal Contraceptive Use and the Menstrual Cycle in Athletes

Plain Language Statement

October 2020

What is this research about?

This research asks you to complete a questionnaire exploring period prevalence and perceived side effects of hormonal contraceptive use and the menstrual cycle in athletes.

Why are we doing this research?

Research in female athletes is significantly underrepresented in the sport and exercise science literature. In particular, research investigating the influence of the menstrual cycle on athletic performance in strength-trained athletes to date is sparse and of low methodological quality. We expect that this research project will help inform athletes, coaches and future research to address these gaps in our understanding of these important issues.

How will the data be used?

The results we obtain from the questionnaires will be grouped together with those of others in the study. When the study is complete, we would like to submit the grouped results to a scientific journal for publication. A report on the study will also be written.

What will happen if I decide to answer this questionnaire?

You will click through to link that will give access to the online questionnaire. The questionnaire is anonymous and automated. Participation is purely voluntary so you can change your mind at any stage and exit the process without consequence.

How will we protect your privacy?

Your privacy will be protected in a number of ways. Your data will be stored on a password-protected computer, which only the project supervisor will have access to. This data will be anonymized so you will not be identifiable from either the individual or grouped results.

What are the legal limitations to data confidentiality?

Because the survey is anonymous, the data cannot be attributed to you or any of your fellow participants, and therefore are no legal limitations to data confidentiality for consideration.

What are the benefits of taking part in this research study?

There is little immediate direct benefit to you but taking part in this study will add to the growing body of information on current practices employed practitioners and researchers in regards to the influence of the menstrual cycle on athletic performance. We anticipate that these results will inform current practice and future research, which will ultimately benefit all female athletes.

What are the risks of taking part in this research study?

There are no anticipated risks in taking part in this research study.

How will I find out what happens with this project?

When the study is complete, we will disseminate a summary of the findings that this research produces via the social media account of Mr. Nolan, and the School of Health and Human Performance at DCU.

Contact details and further information:

If you have any further questions or queries please forward them to:

Mr. David Nolan, Research Assistant, Responsible for coordination of research
Email: david.nolan52@mail.dcu.ie
Phone: 085 1182564
Dr. Brendan Egan, PhD; Principal investigator for this research and responsible for study design
Email: brendan.egan@dcu.ie

If you have concerns about this study and wish to contact an independent person, please contact:

The Secretary, Dublin City University Research Ethics Committee, c/o Research and Innovation Support, Dublin City University, Dublin 9. Tel 01 700 8000

Thank you taking the time to consider participating in this research study. We are looking for volunteers to answer a questionnaire exploring period prevalence and perceived side effects of hormonal contraceptive use and the menstrual cycle in athletes. This work is being performed by Mr. David Nolan under the direction of Dr. Brendan Egan at the School of Human Health and Performance, Dublin City University. Dr. Egan is a lecturer and member of staff at DCU, and Mr. Nolan is a PhD researcher within the School. This research is funded by an Irish Research Council PhD Studentship to Mr. Nolan, which covers his yearly student fees and provides a monthly stipend. Please read the Plain Language Statement that explains the research in further detail.

1 I have read and understood the Plain Language Statement dated October 2020. Therefore, I consent to take part in this research (tick box)
2 Please tick the box below to confirm that your biological sex is female.
3 Please tick the box below to confirm you are over 18 years of age.
4 What is your age? (To the closest year)
5 What is your nationality?
6 How tall are you? (Answer in meters to the closest cm). Note: 1 inch = 2.54cm. Example: 5 foot 8 inches = 68 inches = (68 x 2.54cm = 172.72cm = 173cm = 1.73m)
7 How much do you currently weigh? (Answer in kilograms to the closest kg) Note: 1kg = 2.2lbs.
8 Are you a competitive powerlifter or a rugby player?
9 What type of federation do you compete in? Please select one. If you compete as both, select the option that describes the majority of your competitions:
10 At what age did you begin to train in Powerlifting? (Years)
11 At what age did you begin to compete in Powerlifting? (Years)
12 Which category do you predominantly lift under?
13 Under the conditions you have indicated in the previous question, what is your best SQUAT (in kg) in competition? Please indicate the bodyweight you were on the day of that competition. Please answer in the format: "xxxkg Squat @xxxkg bodyweight" i.e. 150kg Squat @83.6kg bodyweight"
14 Under the conditions you have indicated in question 4 above, what is your best BENCH PRESS (in kg) in competition? Please indicate the bodyweight you were on the day of that competition. Please answer in the format: "xxxkg bench press @xxxkg bodyweight" i.e. 150kg bench press @83.6kg bodyweight"
15 Under the conditions you have indicated in question 4 above, what is your best DEADLIFT (in kg) in competition? Please indicate the bodyweight you were on the day of that competition. Please answer in the format: "xxxkg deadlift @xxxkg bodyweight" i.e. 150kg deadlift @83.6kg bodyweight"
16 Under the conditions you have indicated in question 4 above, what is your best total (in kg) in competition? Please indicate the bodyweight you were on the day of that competition. Please answer in the format: "xxxkg total @xxxkg bodyweight" i.e. 150kg total @83.6kg bodyweight"
17 How many times did you compete in the last year (including non-official competitions)?
18 Which weigh-in procedure do you most often compete at?
19 On average, how many hours per week do you train?
20 At what age did you begin training for rugby? (Years)
21 At what age did you begin to play competitively in rugby? (Years)
22 What country are you currently playing rugby in?
23 At what level do you currently play rugby?
24 What is the highest level of rugby you have played?
25 On average, how many hours per week do you train?
26 Do you use hormonal contraceptives?
27 Do you use a non-hormonal intrauterine device (copper-based coil)?
28 Have you ever had a period (i.e., a menstrual bleed)?
29 Approximately, what is the length of your menstrual cycle? (Days)
30 How many days does your menstrual (blood) flow last?
31 Is the length of your menstrual cycle variable?
32 If yes, please state the range of your cycle (e.g., 27-33 days). Type "N/A" if not

applicable.

33 Are you amenorrhoeic (you have missed more than three consecutive periods)?

34 If YES, has this been diagnosed/confirmed by a doctor?

35 When did this start (e.g., 18 months ago) Type "N/A" if not applicable.

36 Do you currently suffer from any type of menstrual dysfunction? [Oligomenorrhea: cycle length greater than 35 days]

37 Do you currently suffer from any type of menstrual dysfunction? [Polymenorrhagia: cycle length less than 21 days]

38 Do you currently suffer from any type of menstrual dysfunction? [Menorrhagia: abnormally heavy bleeding during your period]

39 Do you currently suffer from any type of menstrual dysfunction? [Metrorrhagia: irregular episodes of bleeding [between your periods]

40 Do you currently suffer from any type of menstrual dysfunction? [Menometrorrhagia: longer duration of flow occurring at unpredictable intervals]

41 Please include any details of menstrual dysfunction not listed in question 7 above. Type "N/A" if not applicable.

42 If yes to any of the menstrual dysfunctions listed above, has this been diagnosed/confirmed by a doctor?

43 When did this start? (e.g., 18 months ago) Type "N/A" if not applicable.

44 Do you get side effects (or symptoms) during your menstrual cycle?

45 If YES, please state the symptoms and when they occur: (e.g., headaches on day 2) Type "N/A" if not applicable.

46 What date did your last period (bleeding) start? [e.g., 12/08/20]

47 Which type of hormonal contraception do you currently use (please tick your answer)?

48 Who prescribes your contraceptive? (e.g., family doctor, sports doctor, specialist)

49 How long (years or months) have you used this method of contraception?

50 If you use an oral contraceptive, do you have your 7 pill-free days? Please tick the answer that applies to you:

51 If you use an oral contraceptive, what date did you begin taking your current pack of pills? [e.g., 12/08/20]

52 Do you get side effects (or symptoms) because of using your contraceptive?

53 If YES, please state the symptoms and when they occur: (e.g., headaches on day 2 of pill taking) Type "N/A" if not applicable.