Assessing knowledge of Relative Energy Deficiency in Sport (REDs) in health professionals, athletes and coaches.

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Attestation of authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor used artificial intelligence tools or generative artificial intelligence tools (unless it is clearly stated, and referenced, along with the purpose of use), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning

Chapters 2 and 3 of this thesis represent stand-alone papers submitted to a peer-reviewed journal for consideration for publication. My contribution and the contribution by the various co-authors to each of these papers are outlined in the "candidate contribution to co-authored papers" table. All co-authors have approved including the joint work in this Masters' thesis.

Lauren Mackessack-Leitch
28/02/2025

Candidate contribution to co-authored papers

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Abstract

Relative energy deficiency in sport (REDs) is a syndrome characterised by impaired physiological function due to an extended period of low energy availability (LEA). LEA occurs when energy intake fails to meet the demands of exercise, triggering a cascade of negative health issues. Up to 60% of physically active women may experience menstrual irregularities in their lifetime, with LEA affecting between 22-58% of females, with some papers even estimating higher levels of LEA in the research (1-4). During periods of energy insufficiency, the body prioritises specific physiological systems, leading to negative effects on health and performance (5). Key concerns associated with REDs include bone stress injuries, hormonal and immune dysfunction, and negative psychological responses, potentially resulting in serious clinical outcomes like amenorrhea, eating disorders, and osteoporosis (5, 6). Social pressures to achieve a particular body shape and psychological factors can further exacerbate the condition.

Firstly, through a systematic review, this thesis explored the current knowledge of REDs among athletes, coaches, and healthcare professionals. By identifying gaps in the existing literature, the research sought to contribute additional data and findings to enhance the current area of knowledge and further recommendations to improve this topic. The systematic review of nine eligible papers determined a lack of knowledge about REDs due to limited education regarding REDs across all subgroups of athletes, coaches, and healthcare professionals. However, the review was limited in scope, reflecting the current poor state of research on this topic.

Secondly, 471 athletes, 29 coaches, and 134 healthcare professionals were surveyed, and the results reinforced the lack of knowledge surrounding REDs which was reviewed and discussed within this thesis. The study showed that 38.5% (n=329) of individuals learned about REDs independently, reflecting the current lack of courses and educational systems. This was apparent from the 49.3% of athletes who noted they did not feel supported by their coach or healthcare professionals, which is understandable considering that 70% of coaches and healthcare professionals reported not feeling confident in REDs referral pathways and discussion symptoms. As athletes are among the highest-risk groups and there are social pressures to maintain a particular physique, it is crucial to understand the knowledge and awareness that healthcare professionals, coaches, and athletes have on REDs.

This thesis review and research data on REDs has identified gaps in education and support that need to be addressed to better support athletes. Additionally, the review found that informative resources are lacking across healthcare professionals, coaches, and athletes, with both systematic reviews and surveys indicating a demand for improved pathways to provide better overall care and education.

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Sincere thanks are given to my supervisors, Patria, Jacinta, and Stacy, for their encouragement and knowledge. Completing this master's has been a very fulfilling and personal journey, and I appreciate your expertise and patience. Thanks to my family for their support, particularly my soon-to-be husband, Luke, who has supported and motivated me throughout the process.

Ethics approval

Ethical approval for the survey study was reviewed and accepted by the Auckland University of Technology Ethical Committee (AUTEC) on 6th May 2024 for three years until May 2027. Approval code: AUTEC 24/117.

Contents

List of tables and figures

List of abbreviations

PRISMA = Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

HCP = Healthcare professionals

REDs = Relative energy deficiency in sport

LEA = Low energy availability

GP = General practitioner

OTS = Overtraining syndrome

Definitions

Relative energy deficiency (REDs)

REDs is a syndrome characterised by impaired physiological function due to low energy availability (LEA) (5-8). LEA lacks a universally defined criterion, and detection relies predominantly on reviewing the physiological outcomes and functional impairments contributing to this development. It arises when the energy intake is insufficient to meet the energy expended during exercise (5, 6). Without appropriate intervention strategies, prolonged LEA can lead to the development of REDs (5, 6, 9). This condition is linked to numerous acute and chronic health issues, which elevate the risk of injuries and certain illnesses (10).

During prolonged energy deficiency, the hypothalamic cyclic release of gonadotropin-releasing hormone (GnRH) decreases, impairing the anterior pituitary's release of gonadotropins. In women, this causes a reduction in the rhythmic release of the follicle-stimulating hormone (FSH) and luteinising hormone (LH), leading to hypoestrogenism, consequentially resulting in functional hypothalamic amenorrhea (11, 12). Hypothalamic amenorrhea is clinically diagnosed when a woman has not had a period for more than three months, leading to adverse effects on bone density and microstructure. The decrease in oestrogen contributes to the inhibition of osteoblasts and the growth of osteoclasts, which can increase the occurrence of stress fractures (13).

Chapter 1: Introduction

Rational for the thesis – Personal view

The motivation for this thesis came from a personal experience with the lack of education and knowledge in healthcare surrounding REDs. I have been involved in sport my whole life, representing Great Britain in figure skating until I was 18, and then in my early twenties, I got involved in endurance racing. Whilst training for my first Ironman triathlon, I experienced amenorrhea for more than six months, accompanied by fatigue, poor mood, and a noticeable decline in performance. When I consulted my General practitioner (GP) about these symptoms, they initially dismissed my concerns, suggesting that such changes were regular for women and that perhaps I was just stressed.

As a physiotherapist, I knew I needed to advocate for myself and push for further investigation. A blood test revealed clinical signs of REDs, but my GP did not follow up, so a colleague introduced me to this topic, and I researched my blood panel and symptoms to find out how best to treat this. I had never learned about REDs at university, nor was I aware of it as a figure skater, nor had I heard of this during the numerous conferences I attended for high-performance sports as an athlete and coach. I had to do extensive research and invest significant time and money to understand and address the problem, which involved private dietitians, therapists, and doctors.

Over years of endurance racing, I endured two stress fractures, multiple injuries, and significant strain on my mental and physical health. My early research into REDs revealed that many studies in this field had limitations, such as small sample sizes, a focus on single sports, or a lack of rigorous methodology. Additionally, online advice was inconsistent, making it difficult to discern what to believe. When I sought help from doctors, many were unfamiliar with what REDs was, let alone give me sound advice. These gaps in knowledge further highlighted the need for more robust research in this critical area and to find out how to make it more accessible to everyone. My hope from this thesis and research is to provide a talking point for athletes, coaches, and HCP to make REDs a common topic discussed within each group, understand the level of knowledge and prevent what happened to me and many other athletes.

Background from the literature

REDs is a syndrome characterised by an extended period of impaired physiological function due to LEA (5-8). LEA occurs when energy intake is inadequate to compensate for the energy expended during exercise. LEA does not have a universally established criterion, and its detection primarily depends on evaluating physiological effects and functional impairments (5, 6). LEA is considered manageable up to a specific threshold; typically, 45 kcal/kg of fat-free mass per day is required to provide sufficient energy availability, with 30-45 kcal/kg of fat-free mass possibly inducing LEA and is only suggested short-term for

athletes (10, 14). Furthermore, if the individuals go below 30 kcal/kg of fat-free mass, they can show serious health implications even after five days (15). However, subsequent research has shown that this uniform threshold does not apply to everyone, as the effects of LEA can vary significantly between individuals (16). The characteristics of LEA, along with environmental and lifestyle factors, influence the outcomes of REDs (5, 17). If an individual sustains a prolonged period of LEA, this could lead to the development of REDs. It highlights that during periods of energy insufficiency, the body's energy reallocation can affect different physiological systems, with some being prioritised as essential, reducible, or nonessential (5, 17). This prioritisation can differ among athletes and within an individual athlete over time (17). Additionally, social pressures to attain a specific body shape, along with psychological factors such as low mood, body dissatisfaction, and anxiety, can further contribute to the progression of this syndrome (10).

Energy deficiency reduces the hypothalamic pulsatile release of gonadotropin-releasing hormone (GnRH) and impairs the anterior pituitary's release of gonadotropins. In females, the decreased pulsatility of follicle-stimulating hormone (FSH) and luteinising hormone (LH) causes hypoestrogenism, resulting in functional hypothalamic amenorrhea and reduced bone mass (11). Hypothalamic amenorrhea is clinically diagnosed when a woman has not had a period for more than three months, which can contribute to adverse effects on bone density and microstructure (13). The decrease in oestrogen contributes to the inhibition of osteoblasts and the increase of osteoclast activity (13, 18). Additionally, LEA disrupts other hormonal pathways, leading to various physiological implications. These include alterations in thyroid hormone signalling, leptin levels, the growth hormone/insulin-like growth factor-1 axis, carbohydrate metabolism, and the balance between sympathetic and parasympathetic tone (11). In males, energy deficiency is correlated to reduced testosterone levels, which can negatively impact bone health and resting metabolic rate (19).

Key concerns include compromised bone health, reproductive issues (such as menstrual irregularities and reduced libido), immune dysfunction, cardiovascular problems, gastrointestinal dysfunction, and declines in mental health and other psychological components (6). Health impacts of REDs encompass a spectrum from bone stress injuries and hormonal and immune dysfunction to negative psychological responses such as increased depression and disordered eating. These issues can vary significantly, potentially resulting in serious clinical consequences outcomes such as eating disorders, osteoporosis, cardiovascular and gastrointestinal decline, and amenorrhea (5, 6, 8). The performance consequences of REDs can vary, but commonly reported issues include poor concentration, impaired judgment, irritability, and decreased adaptation to training load, which increases the risk of injury (5). Up to 60% of physically active women may experience disturbances in their menstrual regularity throughout their lifetime (1, 2).

Aim of thesis and research question

This thesis aimed to investigate the current knowledge of REDs among athletes, coaches, and healthcare professionals (HCP). Therefore, the research question posed and answered in this thesis was: What is the current knowledge of REDs among athletes, coaches, and HCP?

Thesis structure

This thesis follows a manuscript format, whereby two chapters (two and three) were papers prepared for publication. These chapters have been presented in the format required of the journals to which they were submitted, resulting in some repetition of information throughout the thesis. Although it can be presented individually, there is a definitive link between these chapters; each is preceded by a prelude linking chapters and providing cohesion. Each of the manuscripts serves to answer the research questions posed above.

This thesis consists of four chapters. Chapter 1 provides background information on REDs and current research, acknowledging the gaps in knowledge that gave rise to this thesis. Chapter 2 systematically reviews current REDs literature, looking at the knowledge of coaches, athletes, or HCP. The research was minimal, and the cohorts were small. The EBSCOHealth databases, Scopus database, and Google Scholar were searched, and all article types published since 2014 were reviewed.

Chapter 3 presents a mixed quantitative/qualitative study from a survey distributed globally to HCP, coaches, and athletes over 18 years old. The survey was made through Qualtrics and distributed through social media platforms and posters. Data analysis provided insight into the current knowledge of HCP, coaches, and athletes surrounding REDs. Question four of this thesis was answered in gathering and interpreting this information, and future directions were recommended.

Chapter 4 presents a summary of the results and limits of this thesis, as well as suggestions for more research and closing remarks. The included manuscripts as chapters have been cleared of all reference lists, and all cited materials are presented in the reference section of the thesis.

Prelude to Chapter 2

This Chapter 2/Manuscript 1 provides a comprehensive review of the current literature regarding the knowledge of REDs among athletes, coaches, and HCP. With the increasing participation of females in sport, there is a critical need for enhanced understanding and education on key syndromes affecting athletes. The research on REDs is limited, and its prevalence, particularly among female athletes, is alarmingly high. HCP and coaches require more precise guidelines and a deeper understanding of REDs to identify symptoms before they become detrimental to athletes. Moreover, athletes need greater awareness of symptoms that necessitate medical attention and know when help is required. A systematic review of the existing literature on this topic was essential to identify current knowledge gaps and to guide future research efforts.

The search strategy was developed and executed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

Only studies published in English and peer-reviewed since 2014 were included, focusing on addressing three key research questions. First, studies that reported the level of knowledge on REDs in at least one of the groups (HCP, coaches, or athletes) were examined. Secondly, data from these studies were analysed to identify trends within each group. Finally, the limitations identified in the studies were documented to inform the design of more comprehensive future research.

This review provided relevant information on the current knowledge and trends surrounding REDs. This review will help guide future studies and show gaps in where education could be required.

Chapter 2: Knowledge of relative energy deficiency in sports (REDs) amongst healthcare professionals, coaches, and athletes: A systematic review

Overview

Purpose: To review the literature on knowledge of relative energy deficiency in sports (REDs) amongst healthcare professionals, coaches, and athletes.
Methods: The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement was used for the systematic review. The comprehensive search strategy covered a range of databases (last search 5th April 2024) using an inclusion criterion with “RED-S or relative energy deficiency or low energy availability or energy deficiency” and “knowledge or education or understanding or awareness” and/or “survey or questionnaire". The primary variable was "knowledge" regarding REDs. The Critical Appraisal Skills Programme (CASP) checklist assessed paper quality. Key themes were collated and discussed.
Results: Nine papers met high-quality standards by CASP criteria but lacked generalisability due to small sample sizes or focus on specific sports. Females exhibited a higher awareness of REDs than males. Individuals diagnosed with REDs were more educated on REDs. REDs was predominantly seen in females whose body composition was a significant aspect of their sport or performance. Coaches with female athletes or coaches who were female themselves demonstrated greater knowledge. Education positively impacted athletes, enhancing their nutrition and body composition knowledge.
Conclusions: Despite individual awareness, there was insufficient knowledge, education, and management of REDs in active individuals. Thus, comprehensive education and awareness initiatives are needed to enhance the prevention and treatment of REDs across diverse sports populations. Suggested improvements include formal education for healthcare professionals, broadening perspectives among coaches, promoting greater inclusivity and increasing understanding in sports education.

Introduction

REDs defined

Relative energy deficiency in sport (REDs) is a syndrome categorised by a compromised physiological function resulting from low energy availability (LEA) (5-8). LEA develops when energy intake falls short of energy expended during exercise; however, if not addressed with early intervention strategies, over time, it can lead to the development of REDs due to inadequate early intervention strategies (5, 6, 9). There are numerous acute and chronic health issues associated with REDs, which further increase the risk of injury and illness (10). Some of these concerns include a decline in bone health, reproductive (menstrual irregularities, low libido), immune dysfunction, cardiovascular, and gastrointestinal dysfunction, as well as a

decline in mental health and other psychological components (6, 19). These components can appear on a spectrum that varies from optimal health to serious clinical outcomes, including amenorrhea, eating disorders, a decline in heart and gut health, and osteoporosis (5, 6, 20). Up to 60% of physically active women may experience menstrual irregularity, in particular, endurance athletes within their lifetime (1, 2). However, some papers report that 100% of athletes within their research have LEA, and up to 80% of athletes are at risk of REDs (4, 12, 21-23).

The REDs physiological model provides a framework to develop our current and future understanding of the effects of LEA on various body systems in individual athletes. It considers specific moderating risk factors leading to various health and performance impairments (5, 17). The model takes a 'systems biology' perspective to explore how individual characteristics of LEA and various moderating factors specific to each athlete, their environment, and lifestyle may impact REDs outcomes. The model underlines that during periods of energy insufficiency, the body's energy reallocation can affect different physiological systems, with some systems being prioritised, essential, reducible, or nonessential (5, 17). This can differ between athletes and within an individual athlete over time (17). Comparisons of body image and social pressures to achieve a specific body shape, along with psychological components such as low mood, body dissatisfaction, and anxiety, can also contribute to the progression of this syndrome (10).

The problem – Lack of understanding of REDs by healthcare professionals

LEA and REDs is often overlooked within healthcare and sports (10, 24). LEA lacks a universally defined criterion, and detection relies predominantly on assessing the physiological outcomes and functional impairments contributing to this development (5, 24, 25). The primary prevention of REDs involves minimising exposure and reducing behaviours associated with LEA, then identifying and treating early signs and symptoms related to health or performance (26). If REDs advances, it becomes a clinical issue requiring short or long-term medical intervention. Some serious factors that aid in prevention include increasing energy intake, reducing exercise-related energy expenditure, discussing other contributing factors around load, overall diet, attitudes around food, social media pressures and disordered eating habits (7, 27).

Performance consequences of REDs can vary; however, commonly reported are poor concentration, impaired judgment, irritability, and decreased adaptation to training load, resulting in increased injury risk (5). Health may also be impacted by REDs, resulting in bone stress injuries, hormonal and immune dysfunction and negative psychological responses such as increased depression and disordered eating (5, 8, 10).

Athletes with REDs may present with varying symptoms, as the syndrome affects individuals differently (3, 17). Therefore, understanding awareness among distinct healthcare sub-groups is crucial to identifying knowledge gaps (28). Research is required to deepen how we can increase expertise surrounding REDs,

facilitate ongoing refinement of the REDs model, and formulate comprehensive guidelines for prevention, identification, and treatment (5, 7).

Identifying early signs of REDs in athletes from coaches and HCP is vital to reduce the further progression of the syndrome, which can improve longevity in sports and long-term health; thus, understanding barriers and limitations within these fields is essential.

Study purpose

This study aimed to investigate the literature on knowledge of REDs among HCP, coaches, and athletes.

Methods

The procedure used for this systematic review was registered in advance on Prospero (CRD42024509394).

Literature search methodology

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were utilised to assess and demonstrate the integration of papers exploring the existing understanding of REDs within three subgroups of HCP, athletes and coaches. This allowed data collection, literature search, clinical recommendations, and scope for further research to be subject to the overall findings.

Search strategy

The EBSCO Host was utilised to search databases Science Citation Index Expanded, Social Sciences Citation Index, MEDLINE, CINAHL Complete, Scopus®, SPORTDiscus with Full Text Academic Search Index Complementary Index, Bloomsbury Fashion Central. To identify studies surrounding this topic, a search with keywords with the Boolean operators ('AND', 'OR') was utilised: (knowledge OR education OR understanding OR awareness) AND (red-s OR relative energy deficiency OR low energy availability OR energy deficiency) AND (athletes OR sports OR athletics OR performance) AND (Survey OR Questionnaire). The last search date was the 5th of April 2024. Manual searching of reference lists and the 'Cited by' tool on Google Scholar were used to identify additional articles.

Study selection

After databases were searched, all potential titles and abstracts were screened (by LML), and studies were excluded if they did not meet the agreed-upon criteria. Studies were included in this review if: 1) Knowledge surrounding REDs was the key theme in the study; 2) A qualitative approach to extract themes and data was used; 3) At least one of the three subgroups being assessed was included; 4) They were published within the last ten years. Studies were excluded if: 1) It was over ten years old; 2) Full text was

unattainable; 3) It was not in English; 4) It was not peer-reviewed; 5) It did not use REDs knowledge as its central theme. Several studies were excluded as they focused on nutrition, menstrual dysfunction, bone health or other tangents of REDs. A study was retained if it met the agreed quality criteria.

Athlete classification

To be considered an "athlete" and eligible for inclusion in this review, criteria obtained from McKay, Stellingwerff (29) was used. The criteria categorised athletes into tiers from one to five, with tier one excluded as it pertains to sedentary individuals. Higher tiers represent increased activity levels, with tier five encompassing Olympic/world-class athletes. The decision to encompass a range of active individuals came from recognising that many amateur athletes need more learning surrounding their health concerning training and more resources than professional athletes. Comparing athletes across tiers could reveal significant themes during data analysis, such as their knowledge and level of support.

Healthcare classification

The HCP in the included studies actively worked with athletes, both amateurs and professionals. The categorisation divided HCP into five groups for subgroup analyses: 1) HCP – medical doctors, physiotherapists, nurses, midwives, dentists; 2) Health associate professionals – medical, pharmaceutical and dental prosthetic technicians; 3) Personal care workers in health services - healthcare, personal care assistant; 4) Support personnel and health management - health service manager, social work and counselling professionals; and 5) Additional health service providers that are not classified elsewhere– medical interns, armed forces medical technicians.

Coach classification

To classify coaching, all participants in the included studies had formal coach qualifications and were actively training a team or athlete. Some frameworks within coaching have an accreditation pathway, which some studies utilised to give more accurate and higher-quality findings that can be compared across studies.

Data extraction

The lead author (LML) extracted data from included studies, and a co-author (PH) checked the data. No conflicts arose between the authors' data analyses. Data extraction included study design, participant numbers and characteristics (age, sex), and study characteristics (data collection methods, sex differences, and type of sport).

Assessment of study quality

The CASP (30) checklist was used to evaluate the quality of each paper (Table 2.1). Using CASP promoted evidence-based decision-making and enhanced the ability to discern each paper's strengths and limitations and allows for better transparency when reviewing research design (31). The 10 items in the qualitative analysis addressed the research aims, qualitative methodology, research design, recruitment strategy, data collection, the association between researcher and participants, ethical issues, data analysis, statement of findings, and how valuable the research was. However, CASP has been deemed less sensitive in comparison to other tools such as the evaluation tool for qualitative studies (ETQS) which is thought to have better validity overall (31-33).

The one study (34) that used a randomised controlled trial (RCT) was analysed with the CASP framework checklist (35). The 11 items in the analysis addressed the research question, randomised assignment of participants to interventions, participants accounted for at the conclusion of the study, participants 'blind' to the intervention, investigators 'blind' to the intervention administered to participants, and those assessing or analysing outcomes 'blinded'. Additionally, it assessed if study groups were similar at the beginning of the study, if each study group received the same level of care, if the effects of the intervention were reported comprehensively, and if the accuracy of the estimate of the intervention or treatment effect was detailed. Additionally, the benefits of the experimental intervention outweighed the harms and costs, if the results were applied to the local context, and it was considered whether the experimental intervention provided more significant value to the people in care compared to any existing interventions.

Both checklists provided analysis of overall quality and bias risk by screening each paper for validity and quality. This checklist can be found in Appendix B.

Results

Studies extracted

Of the initial 100 studies identified, 35 duplicates were removed. A further 21 studies were removed after screening by title, and 26 were removed after screening by abstract. After the eligibility assessment of full-text articles, 11 additional studies were excluded due to lack of relevance or failure to address the research question (n=7) or not including full text (n=4). Data from nine studies were included in this review for analysis (Figure 1), with quality ratings in Table 2.1 and study characteristics in Table 2.2.

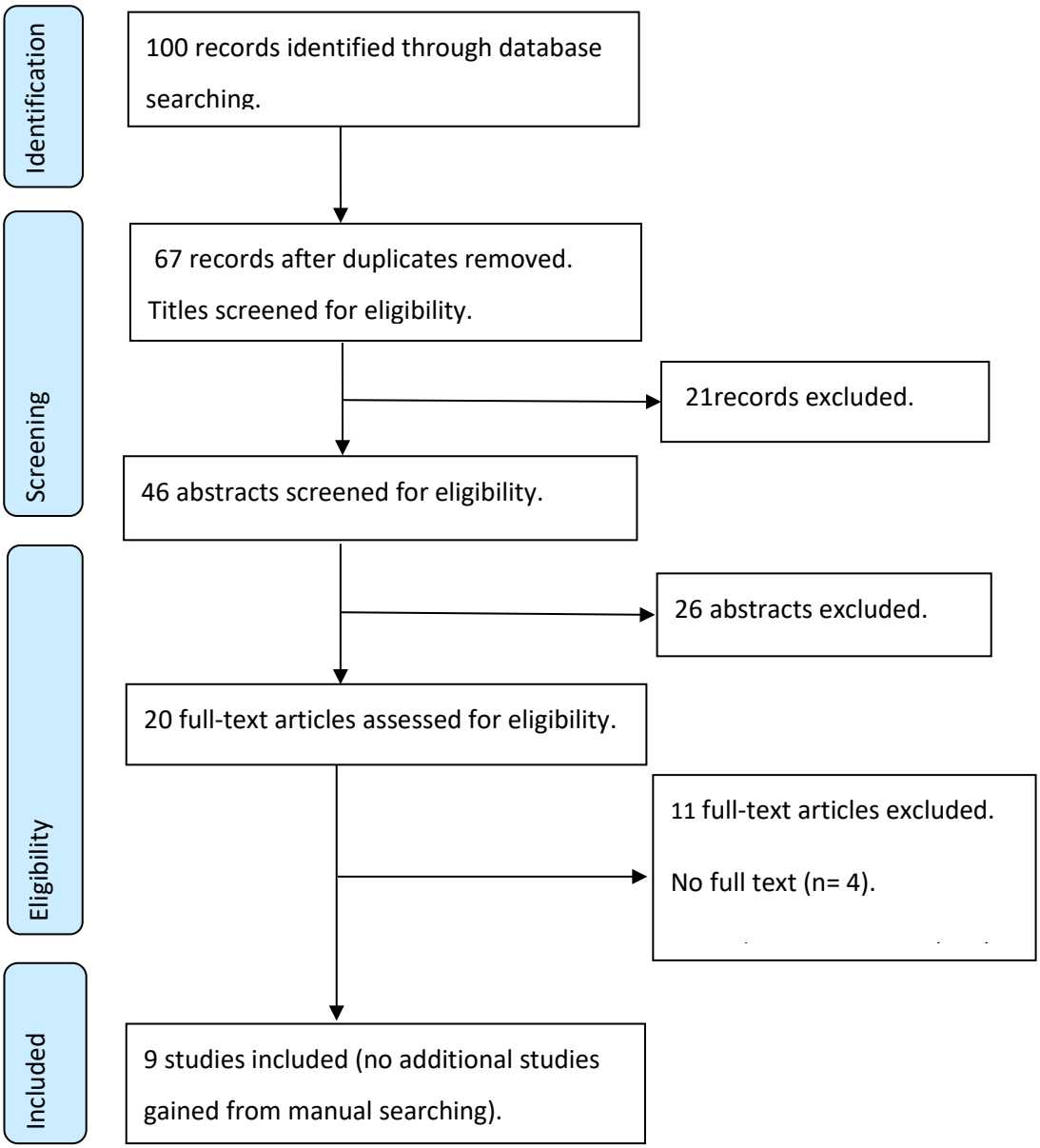

Figure 1: Flow diagram of identification, screening, eligibility, and study inclusion of previously published studies.

Table 2.1: Critical Appraisal Skills Programme (CASP) quality ratings of the nine studies

CASP	1	2	3	4	5	6	7	8	9	10	
(24)	Y	Y	Y	Y	Y	CT	Y	Y	Y	Specific to lightweight rowers and rowing physios' knowledge.	
(25)	Y	Y	Y	Y	Y	N	N	Y	Y	Focused on nutrition and not signs/symptoms of REDs.	
(36)	Y	Y	Y	Y	Y	CT	Y	Y	Y	Specific to female cross-country runners, the sample group of coaches was mainly female but generally male coaches in this sport.	
(37)	Y	Y	Y	Y	Y	CT	Y	Y	Y	Only female cross-country runners have low generalisability to overall athletes.	
(20)	Y	Y	Y	Y	Y	Y	Y	Y	Y	A small cohort of healthcare professionals, Y/N/T/F questions were only used.	
(27)	Y	Y	Y	N	Y	Y	Y	Y	Y	Showed gaps in female education in a small cohort.	
(8)	Y	Y	Y	Y	Y	N	Y	N	Y	Showed the need to educate coaches and ensure REDs can be treated and picked up.	
(28)	Y	Y	Y	Y	Y	Y	Y	Y	Y	A large cohort looked into healthcare, showing limitations and where education may be needed.	
CASP-RCT	1	2	3	4	5	6	7	8	9	10	11
(34)	Y	Y	Y	N	Y	Y	Y	N	Y	It used a small age range of athletes, which could affect generalisability to the overall population.	Y

Y = Yes; N = No; CT = Cannot tell; CASP-RCT had an 11th item.

Table 2.2: Key characteristics of the nine studies that examined REDs knowledge.

Reference	Methods; Focus	Participants characteristics, age (mean±SD)	Findings/overall comments
Gillbanks et al. (2022) (24)	Survey; Knowledge and management of REDs from the perspective of lightweight rowers and physiotherapists.	12 Physiotherapists (6F, 6M), mean 6±5.95 years' experience working with rowers; 22-64 y/o. 12 lightweight rowers (8F, 4M), 3.58±2.08 years lightweight rowing; 19-24 y/o.	Five key themes: 1) insufficient knowledge of REDs; 2) inadequate REDs education; 3) inappropriate management of REDs; 4) referral to other health professionals; and 5) prioritising performance over health.
Hamer et al. (2021) (25)	Scoping review; REDs and LEA-related content provided by Australian NSOs within coaching accreditation programs of popular endurance sports.	Cycling Australia, Athletics Australia, Swimming Australia, Triathlon Australia, Rowing Australia.	Need for REDs education in Australia's coach accreditation pathways for endurance sports. Barriers included limited time, resources, and coaches' existing knowledge and beliefs. Despite challenges, NSO staff expressed enthusiasm for incorporating REDs content into the coaching curriculum.
Lodge et al. (2022) (36)	Survey; Knowledge, confidence, and educational impact of identifying, screening,	275 female collegiate cross-country athletes 20±1 y/o, 55 collegiate cross-country coaches 34±9 y/o, 30 athletic	Female cross-country athletes had lower mean scores in knowledge (25.00±5.27), confidence (95.42±28.83), and educational impact scores (EIS) (18.81±7.05). Coaches had higher mean scores (26.92±5.02, 111.35±24.14, and 22.41±6.33), and athletic trainers (Ats) had even higher mean scores

	treating, and preventing the Triad or REDs in cross-country runners.	trainers working with cross-country teams 36±11 y/o.	(28.66±4.02, 117.67±22.53, 23.93±5.69). Score differences between female athletes, coaches, and Ats were statistically significant ($p<0.05$). Female cross-country athletes scored lower than coaches and athletic trainers in knowledge, confidence, and educational impact. There were no significant score differences between coaches and athletic trainers. Emphasised the importance of education in addressing knowledge gaps related to female athlete triad and REDs. Called for improved prevention and treatment methods and meaningful policy changes to safeguard athletes.
Lodge et al. (2023) (37)	Online survey; Differences in Educational Impact Scores (EIS), as product of knowledge and confidence scores related to Triad and REDs. Associations between EIS and participant characteristics were examined.	275 female cross-country runners 20±1 y/o.	Weak correlation between peak career mileage and EIS ($r=0.195$; $p=0.010$). Significantly higher EIS for athletes with a related academic area of study (21.91±5.16) than those without (16.11±5.54). Significantly higher EIS for athletes with Triad and REDs diagnoses (21.69±5.85 and 22.58±6.82 vs. 16.80±6.54 and 17.20±6.34, respectively) than those without. EIS was higher in individuals who received Triad education (21.03±6.86) than those who did not vs. 18.12±6.82). Significant findings between peak career mileage and Triad diagnosis ($p=0.005$). Participant characteristics included years of running experience, age, bone stress injury history, division level participation, academic area of study, and Triad or REDs education.

Pai et al. (2022) (20)	Online survey; Assessed knowledge of signs and symptoms of REDs in sports among healthcare professionals and physically active individuals.	74 physically active individuals 31.5±12.5 y/o (66F, 8M). 91 healthcare professionals 34.8±12.2 y/o (80 F, 11 M).	Expert responses indicated over 80% acceptability and pretesting through interviews affirmed good content and face validity. Item response analysis led to removing six items due to low discrimination ability. Validity was confirmed by significantly higher knowledge scores in health professionals compared to non-health professionals, with a mean difference of 2.8: 1.9-3.7 (95% CI).
Schofield et al. (2022) (27)	Semi-structured interviews conducted individually and face-to-face or via Zoom. Coaches' responses in their practices related to LEA and REDs were discussed.	9 coaches 28-59 y/o (2 F, 7 M) from 4 sports: 1 athletics, five cycling, two triathlon/ironman, one weightlifting; average 15 years coaching experience.	Elite coaches have been adopting proactive approaches to address sensitive topics in women's sports. Challenges included more women-specific coaching education, communication issues, and resistance from some coaches. Trust and respect were crucial for initiating open conversations about sensitive health issues. Proactive coaching positively impacted athlete health and performance. However, a feminist post-structural approach warns about potential contradictions in coaching practices and language. It highlights the importance of critically examining sources of knowledge, avoiding sex essentialism, and considering the unintended consequences in coaching practices. Ongoing research is needed to understand sportswomen's responses to sex-responsive coaching practices and their potential impact on their health. Lack of female-specific education for coaches preconceived ideas that weight gain could negatively impact the athlete, and difficulty in having critical conversations with their

			athletes about weight and diet with the concern things may be taken negatively.
Stewart et al. (2023) (8)	Face-to-face interviews; over five weeks; lasted 55 to 70 mins; Athlete's perspective of coach's role when working with ultrarunners experiencing REDs.	2 female ultra runners, 40s y/o (2-5 five years of ultrarunning experience).	Emphasised need for improved coach education to enable coaches to provide appropriate support at all stages of REDs. Suggested incorporating multiple sources of information, including athlete input, to enhance the coach's value, benefiting recovery and ongoing ultrarunning post-REDs. Emphasised the coach's role in developing strong relationships with athletes and experts involved in recovery.
Verhoef et al. (2024) (28)	Online questionnaire; Awareness and knowledge of healthcare professionals (physiotherapists, general practitioners, gynaecologists, sports physicians, orthopaedic surgeons) on REDs.	799 healthcare professionals. 189 physiotherapists 38.6 y/o (37% M, 63% F); 200 general practitioners 40.41 y/o (26.5% M, 73.5% F); 281 gynaecologists 41.53 y/o (16.4% M, 83.6% F); 43 orthopaedic surgeons 42.33 y/o (69.8% M, 30.2% F); 86 sports physicians 41.28 y/o (47.7% M, 52.3% F).	Only 22% were aware of REDs. Sports physicians showed the highest awareness (92.9%), and general practitioners had the lowest awareness (10.1%). Sports physicians scored highest on knowledge (mean 8.9), while physiotherapists scored lowest (mean 5.7). 57.6% felt competent discussing REDs underlying problems, but only 7.4% felt qualified to treat REDs. 46.6% of gynaecologists suggested starting oral contraception, which masks amenorrhoea symptoms but does not address the underlying cause of low energy availability. Highlighted low awareness and knowledge among participating health professionals, emphasising the need for further education on REDs, particularly for physiotherapists, general practitioners, gynaecologists, and orthopaedic surgeons.

Tektunalı Akman et al., (2024) (34)	Randomised controlled trial. Impact of nutrition education: Group 1 received six nutrition education sessions, and Group 2 received none. Outcomes were re-tested to see if education impacted results.	83 female athletes aged 15–18 training over 10 hours per week: 38 control group 17.2±2.6 y/o; 45 intervention group 17.1±1.5 y/o.	At baseline, 63.8% of athletes experienced LEA. Intervention group had significant increases in energy availability (EA) and Sports Nutrition Knowledge Questionnaire (SNKQ) scores, while LEAF-Q scores decreased ($p<0.05$). No notable change in EAT-26 scores between groups. Intervention group showed significant increases in energy intake, weight, fat-free mass, and resting metabolic rate ($p<0.05$). Suggested that nutrition education positively impacted dietary intake, body composition, and nutrition knowledge, increasing energy availability in female athletes over the short term.

y/o=years old; M=male; F=female.

Methods to gather knowledge of RED-S within studies

Four studies gathered data via semi-structured interviews (8, 24, 25, 27). Four studies conducted surveys to gather their data (20, 28, 36, 37) and there was one RCT on education and nutrition knowledge (34).

Overall quality of studies

Although all nine papers were of high quality using the CASP framework, most of them utilised small cohorts, with the smallest cohort being only two participants involved (8), to the largest, having 799 participants (28). All studies focused heavily on female-specific issues and included a mixture of sports, HCP, and coaches. As a result, generalising the findings to a broader population would be challenging.

Sports and healthcare samples

Each study varied the level of athlete used and the sports investigated. Many studies focused on weight-dependent sports like rowing (24), cycling and triathlon (25, 27), or running (8, 36, 37). In one study, participants were not exclusively athletes. Instead, they were individuals who identified themselves as physically active alongside HCP (20). This approach offered a more generalisable perspective on active individuals rather than solely focusing on those considered athletes. Another study exclusively examined

HCP and their knowledge of REDs, predominantly assessing physicians such as GPs, gynaecologists, and physiotherapists (28).

What sub-group each study used

The studies varied in participant types, with three of the nine reviewing HCP (20, 24, 28). Only three of the nine studies exclusively reviewed female athletes (8, 34, 37). Two studies incorporated athletes into their review alongside either coaches or HCP (24, 36). Additionally, two studies (25, 27) only reviewed coaches or coaching organisations. In this review, the diverse range of groups, including age, levels of expertise and sport, facilitated an insightful examination of the current education on REDs within this community.

The only study not to use specific athletes reviewed 74 physically active individuals, alongside 81 HCP to help validate a questionnaire regarding knowledge of early signs of symptoms on REDs (20). Validity was proven by substantially higher knowledge scores in health professionals compared to non-health professionals, with a mean difference of 2.8 (95% CI: 1.9-3.7).

Sex of participants

REDs predominantly affects females. However, it has been suggested that the assessment tools for females are not sensitive enough to identify subtle symptoms in male athletes (38). The apparent female bias of REDs heavily weighted the research outcomes, making the findings less generalisable to the male population.

Discussion

This review analysed the knowledge of coaches, athletes and HCP in various sports. In a study (24) of knowledge and management of REDs for 12 lightweight rowers and 12 physiotherapists, the five key themes that emerged were insufficient knowledge of REDs, inadequate REDs education, inappropriate management of REDs, referral to other health professionals and prioritising performance over health. Our review of nine studies has added key themes of sex differences and sports with body composition requirements. Combining insights from the nine studies revealed a cohesive narrative highlighting challenges in understanding and managing REDs. The overarching theme across the challenges was an evident lack of understanding surrounding REDs, emphasising the necessity for concerted efforts to address and rectify REDs issues to improve athlete health and performance. The consensus of this review showed that REDs is an important healthcare issue that has yet to be analysed worldwide and compared for different groups of individuals who work closely with this syndrome.

Knowledge of REDs by healthcare professionals and coaches

Verhoef, Wielink (28) reviewed knowledge via a survey among 799 participants in differing healthcare professions and found that only 22% of the overall cohort knew what REDs was, exposing a lack of education in areas where many athletes turn for advice and treatment. Sports physicians scored the highest with REDs knowledge, with 57.6% of participants reporting they felt confident discussing REDs. However, only 7.4% of HCP felt qualified to treat REDs. Additionally, 46.6% of gynaecologists preferred prescribing contraceptives rather than adequately assessing menstrual dysfunction. This would mask further REDs symptoms due to false information about menstrual health, as this is not an actual period but a withdrawal bleed from the contraceptive.

Gillbanks, Mountjoy and Filbay (24) conducted a semi-structured interview with 12 physiotherapists and 12 female lightweight rowers. Key emerging themes included insufficient knowledge, inadequate education, inappropriate management, a lack of referrals to other healthcare professionals, and a tendency to prioritise performance over health. The study also found that physiotherapists were more inclined to refer athletes to other HCP. Since athletes often consult physiotherapists more frequently than doctors, competent screening for REDs by physiotherapists is crucial for timely intervention and comprehensive care. Based on these findings, the study suggests formal physiotherapy education and targeted education for athletes and coaches to increase awareness and understanding of REDs (24).

Lodge, Ackerman and Garay (36) surveyed knowledge, confidence, and educational impact score (EIS) of REDs in 355 female cross-country runners, athletic trainers, and their coaches, who were predominantly male. Significant differences were found among the groups, with the lowest scores in athletes and the highest in athletic trainers. Results highlighted the need for education as a primary tool to enhance the prevention and treatment of REDs. Using the same data, Lodge, Ackerman and Garay (37) reported a weak positive correlation between peak career mileage and EIS. Athletes with relevant academic backgrounds or Triad/REDs diagnoses had higher EIS than those with REDs education. There was a significant relationship between Triad diagnosis and peak career mileage. Additionally, coaches had higher scores around education than athletic trainers and athletes, with female cross-country runners scoring the lowest (37). Another study observed knowledge was superior in healthcare groups compared to individuals with no medical background (20).

Education interventions

There was only one RCT on education which examined its impact on the LEA risk of 83 young athletes regarding nutrition and overall nutritional knowledge (34). The study found that when athletes received nutritional education, their awareness of LEA increased compared to the control group. This education improved diet, body composition, and nutrition knowledge, increasing short-term energy availability. Notably, the intervention had a significant effect on instilling positive habits among the 38 young female

athletes within six months, highlighting the crucial role of education in significantly mitigating the risk of REDs.

Hamer, Desbrow and Irwin (25) employed a semi-structured interview approach to assessing coaches across various sports and coaching levels, examining their current training on REDs and the need for REDs education to be part of the coaching curriculum to help increase awareness. Key insights revealed a universal absence of formal training on REDs at all levels. Some coaches expressed concerns about needing more knowledge at performance levels, highlighting challenges in comprehending REDs and articulating discussions. Many coaches struggled with fundamental nutritional understanding, emphasising the need for enhanced education. Improvements were suggested within the study, including formal physiotherapy education and targeted education for athletes and coaches, highlighting a critical need for increased awareness and education about REDs in this population.

Stewart, Allen and Kirkland (8) interviewed two female ultrarunners who had two to five years' experience and had both been diagnosed with REDs. The interview highlighted the need for better education among endurance athletes and coaches due to the strong correlation between their performance and diet and for coach education to support athletes at all stages of REDs. It also emphasised the importance of coaches building solid relationships with their athletes and gaining sound referral systems with experts in this area.

Schofield, Thorpe and Sims (27) conducted semi-structured interviews with nine coaches with an average of 15 years of experience from various sporting backgrounds. They found a lack of female-specific education for coaches, preconceived ideas that weight gain could negatively impact the athlete, and difficulty having critical conversations with their athletes about weight and diet with the concern that comments may be taken negatively. They recommended more female-specific education within sports to provide better care and help female athletes feel more supported.

A consistent finding was the requirement for more education, particularly in coach accreditation pathways and among HCP, calling for comprehensive initiatives to enhance awareness and knowledge of REDs. Many athletes have found minimal support or education around REDs and, therefore, educate themselves on the syndrome, allowing them to acquire more knowledge than others (37). Additionally, individuals educated on nutrition and body composition positively impacted athletes' energy consumption and nutrition knowledge compared to athletes who never got educated ($p<0.05$) (34).

Management

The studies underscored shortcomings in healthcare management and referral systems for REDs, indicating a need for more efficient and coordinated approaches. Inappropriate care and management practices emerged as a shared concern, emphasising the importance of aligning interventions with the best interests of athletes grappling with REDs.

Verhoef, Wielink (28) found that HCP management of REDs was lacking, with only 7.4% feeling confident about treating the syndrome. A survey screening REDs in healthcare revealed that 57% of the 60 respondents faced time constraints affecting their screening efficiency, while 37% reported resource shortages (39).

Referral

It was found physiotherapists reported feeling out of their depth and felt that, as a profession, they lacked education on identifying early signs of REDs and generally tried to refer them to specialists (24). However, many specialist fields also felt a lack of knowledge and support in this area (28). Having simple and quick-acting systems for healthcare and coaches would allow their athletes to be looked after and symptoms to be picked up earlier. No studies within this review investigated what changes could be made to give professionals better referral systems for REDs.

Performance over health

A recurrent theme was prioritising performance over health, suggesting a potential imbalance in the focus on athletes' well-being. Rowers were found to have a culture of prioritising performance over health (24). Some remarks made by the rowers during the interview were comments on restrictive eating due to concerns on making race weight, a lack of acknowledgement from coaches around diet concerns, as well as comments on appearance and prolonged periods of yo-yo dieting, which negatively impacted energy levels (24). Remarks regarding preconceived beliefs that weight gain would directly impair the athlete's performance (27).

Females versus males

Research on REDs revealed a sex bias, with the predominant focus being on females, potentially influenced by assessment tools that may be more female-specific or that females are affected more by REDs. More recent models have encompassed both sexes (7). Overall, female athletes and coaches who predominantly worked with female athletes exhibited greater knowledge and awareness of REDs symptoms than those who did not (36). This discrepancy may arise from the perceived higher prevalence of REDs among female athletes, with its impact on males still unclear. Symptoms in females are generally easier to identify, potentially leading to more frequent diagnoses within this demographic rather than indicating superior education. A recent study on REDs screening reported that females were assessed for REDs more routinely than their male counterparts (55% versus 33%) (39). Overall, females had better awareness of REDs signs than males; however, this could be due to females having more conversations around REDs due to the increased prevalence of this topic within a female athlete environment. The studies

reviewed were also predominantly female-based, potentially skewing results to view females as having better awareness.

Prior REDs

Athletes with a history of REDs were more aware of REDs signs and symptoms (37). Poor diagnosis and symptom identification can affect various systems in the body. In terms of reproductive health, women may experience disrupted menstruation, such as missed or abnormal periods, while men may have a reduced libido (10). Bone health is also impacted, with an increased risk of stress fractures and early-onset osteoporosis (5, 10). Additionally, decreased immunity can lead to more frequent infections and colds (5, 36).

Sports with strict body composition requirements

Weight (or body composition) dependent sports are thought to have a higher risk of REDs prevalence. REDs was seen more in individuals who played sports with strict body composition requirements, such as gymnastics, rowing, ultrarunning and triathlon (8, 25, 27). The emphasis on aesthetic or weight-related performance standards in these sports may contribute to a higher prevalence of REDs. This highlights the importance of recognising the impact of sport-specific demands on athletes' physiological well-being and underscores the need for tailored interventions and awareness campaigns within these disciplines to promote good education about body image and good physical health. Many sports, particularly endurance and weight-dependant sports, have a naturally higher risk of REDs due to the difficulty of fuelling appropriately within the sports' constraints of power-to-weight and the "ideal" morphology for success (7).

Limitations and future research

A fundamental limitation identified in this review was that of the nine studies that met the inclusion criteria, many studies focused exclusively on single sports, small geographical areas, or only included female participants. This restricted the availability of generalisable statistical evidence and limited the findings to broader populations or other sports. Consequently, drawing overarching conclusions about the effectiveness of questionnaires or the prevalence of specific trends became challenging, emphasising the need for more inclusive research. Broadening this research to include larger cohorts with varied sporting backgrounds or professional experiences in differing geographical areas would facilitate the discovery of additional trends and improve comprehension, potentially enhancing the quality of care and enabling earlier interventions.

Conclusions

This review highlighted that females exhibit generally higher awareness of REDs than males, that individuals diagnosed with REDs were more educated on REDs, and coaches with female athletes or coaches who are female themselves demonstrated greater knowledge of REDs. REDs was predominantly seen in females whose body composition was a significant aspect of their sport or performance, and the knowledge and awareness of REDs was lacking across different groups involved in sports, including physiotherapists, athletes, coaches, sports physicians, and gynaecologists. Overall, these findings underscored the critical need for comprehensive education and awareness initiatives to enhance the prevention and treatment of REDs across diverse populations involved in sports. Suggestions for improvement include formal education for HCP, targeted education for athletes and coaches, and increased awareness overall of symptoms.

Prelude to Chapter 3

The literature review of the information gathered in Chapter 2/Manuscript 1 showed that many studies were sport—or healthcare-specific, making it harder to generalise the data and understand where improvements can be made. Therefore, a survey was created and distributed to analyse three groups globally to understand what each group knew about REDs. Chapter three incorporates several questions and findings from the systematic review but broadens the focus to include a larger demographic. Additional questions regarding the current feelings of support within sports, healthcare, and coaching have been added to help provide recommendations and insight on how the current level of REDs can be improved within each category. Of 1,228 individuals, 523 (42.6%) accessed the study using the QR code and 705 (57.4%) through the survey link. This survey study was more extensive and inclusive than any study reviewed in the Chapter 2 literature review and has given a more general view of the current REDs knowledge. The survey utilised mixed quantitative and qualitative data analysis methods to understand and compare the current knowledge within each category.

Chapter 3: Assessing knowledge of relative energy deficiency in sport (REDs) among health professionals, athletes and coaches

Overview

Purpose: To evaluate the knowledge of relative energy deficiency in sports (REDs) among healthcare professionals, coaches, and athletes.

Design: Mixed quantitative and qualitative online survey.

Methods: The Qualtrics-developed survey ran from May 10th to July 8th, 2024. Participants were recruited through online databases (social media platforms and sporting teams) and posters worldwide. They had to fit into at least one of three groups: healthcare (HPC), coaching, or athletes—professional or recreational.

Results: The survey, which had 1,228 initial respondents, revealed that 902 (73.5%) answered at least one question. Overall, 71% reported knowing what REDs was, 11.9% had heard of the syndrome, and 17.1% had not. Females answered more question on REDs correctly compared to males. HCPs answered the most questions correctly compared to the other groups. Although, 70% of coaches and HCPs did not feel supported, with 49.3% of athletes also felt a lack of support around REDs.

Conclusion: There are varying aspects of knowledge and understanding of REDs in healthcare, coaching, and athlete cohorts. The survey results underscored the pressing need for better education and support for coaches and HCPs to effectively address and manage REDs and ensure the well-being of athletes.

Introduction

Relative energy deficiency in sport (REDs) is a syndrome characterised by reduced physiological function following persistent low energy availability (LEA) (5-7). LEA occurs when energy intake is insufficient to meet the energy expended during exercise, alongside the energy needs for daily body system function (5, 6, 9) . This syndrome is linked to numerous acute and chronic health issues, which may elevate the risk of injuries and certain illnesses (10). Key concerns of REDs include physical deterioration, such as bone stress injuries and hormonal and immune dysfunction, and negative psychological responses, such as increased depression, anxiety, and cognitive decline. These issues can vary widely and may lead to severe clinical outcomes, including body dysmorphia, hypothalamic dysfunction, and oestrogen dysregulation. Amenorrhea and bone-related complications arise from the downregulation of the hypothalamic-pituitary-adrenal (HPA) axis, which reduces or flattens the luteinising hormone pulse. This, in turn, decreases the

oestrogen pulse and ultimately results in anovulation, resulting in the absence of menstruation and a decline in bone health, cardiovascular and gastrointestinal health (5, 6).

Furthermore, social pressures to attain a specific body shape, especially within certain sports (40), along with psychological factors such as low mood, body dysmorphia, and anxiety, can further contribute to the progression of this syndrome (10).

As female athletes are among the highest-risk groups coupled with sociocultural pressures to maintain a particular physique, it is crucial to understand the knowledge and awareness that healthcare professionals (HCP), coaches, and athletes have on this topic. Therefore, this survey was conducted to evaluate the knowledge of REDs among HCP, coaches, and athletes.

Methods

Ethics approval was granted on May 6, 2024, in accordance with the Auckland University of Technology ethics committee (AUTEC 24/117). Informed consent was collected from each participant at survey time.

Participants and recruitment

Participants were recruited through social media platforms and posters, accessing the survey via a QR code or link. The survey was open for 9 weeks in mid-2024. Participation was anonymous and voluntary. Responses were monitored, and social media reposting occurred weekly through general and sports pages to ensure regular viewing and participation.

Inclusion criteria were clearly stated in each social media post to ensure appropriate participation. Inclusion criteria were: 1) individuals over 18 years old; 2) be an "athlete" and fit into tiers one (recreationally active) to five (world-class) (29); or 3) be a coach or a HCP (41). Exclusion criteria were: 1) under 18 years old; 2) not fitting into the three groups (athlete, coach, HCP); and 3) Fitting into tier 0 (sedentary) (29).

Outcomes and data collection

Data were gathered through an online survey (supplementary material) conducted on the Qualtrics platform (https://www.qualtrics.com/). Demographics collected included the individual's group, age group, years of practice or in sport, geographical location, race and gender (terminology for this was ‘female’, ‘male’, ‘non-binary’ or ‘prefer not to say’).

The survey included 36 questions in different formats, ranging from quantitative 'true', 'false', ‘neither true nor false’, ‘unsure’ or 'do not know' to qualitative responses. This approach enabled a broader range of data collection and helped identify and understand gaps within each group. The questions were developed from published literature that only used small cohorts, either specific groups, sports or geographical

locations (8, 20, 24, 25, 28, 34, 36). The authors reviewed and streamlined the questions which allowed for various questions that were thought to be important in this topic to be asked. These questions can be seen in Appendix C with the survey questions (questions 14 to 31).

Analysis

All data were exported into a Microsoft Excel spreadsheet (Microsoft Excel, Microsoft Corporation, Redmond, WA, USA). Percentages and weighted averages were calculated using Microsoft® Excel, and free text entries were analysed in NVivo® (NVivo 1.6.2, QSR International Pty Ltd, Burlington, MA, USA). The top fifteen words were tabulated and organised into themes, and word clouds were generated.

Results

The key results are reported here, and additional survey results are provided in the supplementary information.

Participant characteristics

Of the 1,228 individuals who clicked on the survey link, 902 (73.5%) answered at least one question (attrition of 26.6% from initial respondents). The lowest number of responses to a single question was recorded at 661 (53.8% completion), and 754 individuals completed 100% of the survey. The survey took a median of 21.9 minutes to complete.

Of the 879 participants in the final survey cohort who reported their gender, 826 (93.9%) identified as female, 51 (5.8%) identified as male, and 2 (0.2%) identified as non-binary. Given that only two individuals selected this category, non-binary individuals' answers were excluded from the gender findings. However, they were included in all other survey findings.

The participants (n = 768) were aged 18 to 60 (8.6% 18-25 years: n=66; 13.8% 26-30 years: 106; 31.3% 31-40 years: 240; 34.1% 41-50 years: 262; 20.6% 51-60 years: 158; 4.7% over 60: 36).

Of 902 participants who answered at least one question, 471 (52.2%) were professional or recreational athletes, 134 (14.9%) were HCP, 29 (3.2%) were coaches, and 252 (27.9%) fit into more than one group.

The survey's global distribution resulted in 880 individuals reporting from 45 countries. Table 3.1 shows the breakdown of number of participants.

Table 3.1: Country and number of participants in the survey

Country	Number of participants (n)
Australia	86
United States of America	262

New Zealand	79
Canada	240
Europe	75
United Kingdom	100
Other	33

Survey questions

Survey question results are presented with themes for beliefs, attitudes, and knowledge surrounding REDs and how participants learned about REDs.

Of 858 respondents who answered this question, 71% (n=609) knew what REDs was, 11.9% (n=102) had heard of REDs but did not know what it was, and 17.1% (n=147) did not. Of 854 respondents who answered the question on how the learned about REDs, 15.7% (n=134) had never heard of REDs, 8.3% (n=71) had formal training, 8.1% (n=69) learned on a course, 29.4% (n=251) had heard about it, and 38.5% (n=329) learned from their own research.

Beliefs surrounding REDs

Responses to the statement **"REDs is relatively rare and not often seen"** varied by gender. Among 736 females, 92.3% (n=679) believed REDs is frequently seen, while 7.7% (n=57) thought it is rare. Of the 44 males, 75% (n=33) considered REDs frequently seen, compared to 25% (n=11) who thought it is rare. Among the respondents, 401 were athletes, 233 fit into two or more groups, 120 were HCP, and 24 were coaches. Athletes had the lowest correct response rate (88.5%, n=355), while those in two or more categories had the highest (94.4%, n=220).

In examining the statement **"Irregular periods are no cause for concern",** 751 females and 44 males answered. Females had a higher correct response rate (90.5%, n=680) compared to males (77.3%, n=34), disagreeing that irregular periods are not a sign of peak physical condition and should be a cause for concern. Among the respondents, 412 were athletes, 236 fit into two or more groups, 121 were HCP, and 24 were coaches. Most groups scored well, with HCP scoring the highest (95%, n=115) and coaches the lowest (83.3%, n=20). Additionally, 10.2% of athletes (n=42) and 16.7% of coaches (n=4) were unsure.

In response to whether insufficient **“energy intake can contribute to females missing their periods”,** 752 females and 44 males answered. More females (94.1%, n=708) than males (79.5%, n=35) agreed. Among 412 athletes, 236 in multiple groups, 121 HCP, and 25 coaches, most agreed, with HCP having the highest agreement (95.9%, n=116) and coaches the lowest (88%, n=22).

Attitudes surrounding REDs

The survey results showed strong agreement against **"prioritising performance over health".** Among 746 females and 44 males, 74.4% (n=555) of females and 68.2% (n=30) of males disagreed with prioritising performance. Among 408 athletes, 236 in multiple groups, 120 HCP, and 24 coaches, athletes had the lowest disagreement rate (67.6%, n=276), while coaches had the highest (87.5%, n=21).

In response to whether **"comments on weight can potentially cause long-term issues",** 752 females and 44 males answered. An overwhelming majority disagreed, with 100% (n=44) of males and 98% (n=737) of females rejecting the statement. Among 412 athletes, 236 in multiple groups, 121 HCP, and 25 coaches, those in multiple categories had the highest disagreement rate (99.2%, n=234), while coaches had the lowest (96%, n=24).

Knowledge surrounding REDs

With respect to whether **"Males have a higher risk in REDs",** 739 females and 44 males answered. A lower percentage of females disagreed (75.5%, n=558) compared to males (79.5%, n=35). Among 403 athletes, 234 in multiple groups, 120 HCP, and 24 coaches, HCP had the highest correct response rate (79.2%, n=95), while coaches had the lowest (62.5%, n=15).

In answer to whether **"REDs and overtraining are the same",** 738 females and 44 males answered. A lower percentage of females answered correctly (88.2%, n=651) compared to males (90.9%, 40). Among 402 athletes, 234 in multiple groups, 120 HCP, and 24 coaches, athletes had the lowest correct response rate (84.3%, n=339), while HCP had the highest (97.5%, n=117).

Addressing whether **"low libido can be associated in males with REDs",** 745 females and 44 males answered. A lower percentage of females (65.9%, n=491) compared to males (68.2%, n=30) answered correctly. However, a high percentage were unsure; 34.1% (n=254) of females and 31.8% (14) of males. Among 407 athletes, 236 were in multiple groups, 120 were HCP, and 24 were coaches. The athletes had the lowest correct response rate (56.8%, n=231), with 43.2% (n=176) unsure. HCP had the highest agreement (78.3%, n=94), but also significant uncertainty rate (21.7%, n=26).

Regarding the question of whether "stress fractures occur more often in females who miss their period for three or more months than in females who have regular periods", 751 females and 44 males answered. More females (79.9%, n=600) than males (59.1%, n=26) agreed, but uncertainty remained, with 19% (n=143) of females and 38.6% (17) of males unsure. Among 411 athletes, 236 in multiple groups, 121 HCP, and 25 coaches, HCP had the highest correct response rate (90.9%, n=110), while coaches had the lowest (72%, n=18), with 24% (n=6) unsure and 4% (n=1) disagreeing.

Concerning whether **"hormonal contraception should be the primary way of treating females with irregular periods",** 752 females and 44 males answered. More females (87.2%, n=656) than males (68.2%,

n=30) disagreed, but uncertainty remained high, with 11.4% (n=86) of females and 27.3% (12) of males unsure. Among 412 athletes, 236 were in multiple groups, 121 were HCP, and 25 were coaches. The athletes had the lowest correct response rate (83.3%, n=343), with 14.8% (n=61) unsure. Coaches had the highest correct response rate (92%, n=23), with 8% (n=2) unsure.

In response to whether **"it is usual for females to miss their periods when they are active",** 750 females and 43 males answered. A slightly higher proportion of females (93.6%, n=702) disagreed compared to males (90.7%, n=39). Among 412 athletes, 235 in multiple groups, 120 HCP, and 24 coaches, athletes had the lowest correct response rate (90.8%, n=374), while HCP had the highest (97.5%, n=117).

In rating **"confidence in identifying REDs out of 100",** females had a mean score of 44.1 ±27.4, while males had a mean score of 39.8 ±33.1. For confidence in their answers, females had a mean score of 63.8 ±23.9, and males had a mean score of 58.49 ±27.6. HCP had the highest mean confidence score in identifying REDs (51.3 ±27.4), followed by individuals in multiple categories (46.5 ±28.4), coaches (45.3 ±23.8), and athletes with the lowest (38.9 ±26.9). Individuals in multiple categories had the highest mean score (65.94 ±23.6), followed by coaches (65.6 ±16.9), HCP (62.2 ±22.8), and athletes (62.2 ±25.3).

Of the 902 individuals, 771 answered the "**symptoms associated with REDs**" question**.** Among them, 87.8% associated REDs with menstrual dysfunction, 85.7% with increased injury risk, 85.2% with negative mental health impacts, and 84.4% with decreased performance. Additionally, 82.9% linked REDs to sleeping difficulties, 81.6% to increased irritability, and 81.1% to reduced focus. Decreased immunity was identified by 79.6%, weight and body composition changes by 77.4%, gastrointestinal problems by 69.6%, increased cardiac risk by 67.4%, and decreased coordination by 65.6%. Overall, most individuals correctly identified a significant percentage of REDs symptoms that were listed and commonly seen in REDs patients (5, 6).

Support for REDs

In response to whether they **"felt supported in identifying and getting adequate support for REDs,"** 738 individuals answered, including 408 athletes. Of 330 eligible coaches and HCP, 30% (n=99) felt well-supported, while 70% (n=231) felt the system lacked support. Keywords used to describe what participants reported as needed to improve current systems (Table 3.1) were summarised by themes (person, content, education, nurturing, and communication) with the words refer, athletes, coaches, education, doctors and resources being most frequently reported. The total number of coaches and HCP were not data extracted from this survey.

Table 3.2: Cloud of words used when asking for qualitative feedback on support for coaches and HCP

Theme	Count	Weighted percentage (%)	Similar words
Person	38	2.26	athlete, athletes, athletic, athletics
	33	1.96	coach, coaches, coaching
	16	0.95	doctor, doctors
	19	1.13	Health
Content	29	1.72	RED, REDs
	24	1.43	sport, sporting, sports
Education	25	1.49	educate, educated, education
	23	1.37	know, knowing
	17	1.01	resource, resources, resourcing
Nurturing	21	1.25	support, supporting, supportive
	19	1.13	need, needed, needs
	16	0.95	help, helpful, helping
Communication	18	1.07	trained, training
	25	1.49	referral, referrals
	41	2.44	refer, referred, referring
			

The survey asked 558 athletes if they felt supported by their coach or HCP and for suggestions to improve support. Of the respondents, 50.7% (n=283) felt supported, while 49.3% (n=275) did not. Keywords used to describe what participants reported as supporting athletes from the athletes' perspective (Table 3.3) were summarised by the same themes, with the words coach, training, feel, knowledge, information, talk, need, and professionals being the most frequent keywords. Many athletes noted they do not feel comfortable talking to their coach or have enough support.

Table 3.3: Word Cloud of words used by athletes when giving feedback on support for HCP and coaches

Theme	Count	Weighted percentage (%)	Similar words
Person	115	5.36	coach, coached, coaches, coaching, coaching
	21	0.98	professional, professionals
	20	0.93	athlete, athletes, athletic
	20	0.93	Female
	20	0.93	Health
Content	22	1.02	red, reds
	19	0.88	nutrition, nutritional
Education	22	1.02	knowledge, knowledgeable
	18	0.84	inform, information
Nurturing	19	0.88	support, supported, supportive
	27	1.26	feel, feeling
	26	1.21	need, needed, needs
Communication	22	1.02	talk, talked, talking
	18	0.84	discuss, discussed, discussing, discussion, discussions
	51	2.38	train, trained, training, trains
			

Discussion

Our survey on beliefs and attitudes surrounding REDs found that awareness of REDs was high, but knowledge of the syndrome was limited. Females appeared to have a better understanding of the topic than males, however with the small cohort of males we cannot definitively say this and more research with more males would be required. HCP had the most correct answers but were the least confident. REDs in males was poorly detected, and lastly, athletes, coaches, and HCP all felt a lack of support regarding REDs.

Beliefs and attitudes are often metaphorically described as personal “possessions" acquired through life experiences, values, and social influences, which individuals carry throughout daily life (42). They are related but have distinct concepts in psychology and everyday language. Belief can refer to a mental acceptance that something is true or exists and is often based on evidence, experiences or cultural and societal influences (43, 44). For example, believing that exercise is beneficial for health is a belief. While emotions, behaviour, and cognition shape most attitudes, each can vary across individuals and specific attitudes. Some attitudes are primarily driven by emotions, behaviours, and beliefs (45). For instance, a positive attitude toward exercise means you feel good about it, believe it is beneficial, and are likely to engage in it regularly.

Overall awareness of REDs is high, but knowledge of the syndrome is limited

Many individuals had heard of REDs (70%); however, only 8.3% of survey participants received formal training on REDs. The survey indicated that many respondents were unaware of its prevalence and risks, particularly among REDs seen in males. A diagnosis of REDs can be difficult, and many studies have focused on a small geographic or sports cohort, making it hard to say how many individuals are affected by this syndrome precisely (9, 24, 25, 36, 37, 46). Overall, there is a general awareness of REDs across different groups, though there are some differences in the level of recognition depending on the group.

Females were better than males

Overall, females outperformed males in almost every question. REDs is thought to affect more females; therefore, females could have a better understanding due to exposure to REDs and the educational resources are more targeted to females. There were also many questions regarding menstrual cycles, of which males generally have lower knowledge (47, 48). An issue highlighted in the survey was the number of females across various sports with male coaches, indicating a potential requirement for better education and knowledge of male coaches and HCP, given the high prevalence of them supporting female athletes.

HCP performed the best but were the least confident in their answers

HCP achieved the highest scores, with individuals fitting into two or more categories scoring the next highest, then coaches and athletes coming in last. This was possibly due to HCP having a more comprehensive understanding or familiarity with the questions. However, the overall knowledge within all groups had a high proportion of uncertainty, indicating a clear reflection of the poor state of education among all demographics. HCP exhibited the highest mean confidence score in identifying REDs out of 100 (51.3 ±27.4), likely due to their familiarity with the subject. However, it was still considerably low, which reflects their reported lack of support within referral and educational systems. HCP scored an average of 62.2 ±22.6 out of 100 in reporting their confidence in their survey answers. This score was lower than all

other categories. This difference may indicate that HCP were less confident in their answers, potentially due to an awareness of gaps in their current knowledge on the topic and a lack of existing evidence surrounding REDs. On the other hand, athletes, coaches, and individuals fitting into two or more categories may reflect a Dunning-Kruger effect, as their learnings might rely more on non-evidence-based understandings and anecdotes related to REDs and, therefore, have overestimated their knowledge correctly.

REDs in males is poorly detected

Many questionnaires designed to screen for REDs are tailored to female-specific issues, such as menstrual irregularities, which do not apply to males. Alongside poor definitions of LEA for males, males may be able to endure a more extended period of reduced energy than females before showing the more obvious symptoms, such as reporting low libido or decreased testosterone (49). The survey revealed widespread uncertainty across all groups when asked about the correlation between low libido and REDs in males, highlighting the need to understand better the primary indicators for males and the early diagnosis of REDs in this demographic.

While REDs and Overtraining Syndrome (OTS) share many similarities, most survey respondents agreed they are separate syndromes. The main difference is that REDs involve bone pathology, while OTS does not (50). Interestingly, it is thought that OTS is much more prevalent in males compared to females (50). This makes us question if OTS is more prevalent in males or if it is just REDs misdiagnosed, and the current signs, such as low libido for males, are an insufficient indicator for REDs.

HCP and coaches felt they needed more clinical support

Of the HCP and coaches, 70% stated that they required more clinical support and confidence regarding assessing REDs or faced difficulties knowing where to refer patients. This highlights the need for better education and support for coaches and HCP to effectively address and manage REDs, ensuring the well-being of athletes. Further research indicated that more than 85% of coaches reported they would not know how to intervene or recognise the symptoms of REDs (36).

Athletes require more support from their coach or HCP

Athlete responses were nearly split when asking if they felt supported, with 50.7% feeling supported by their coach or HCP. These numbers were not a surprise, given that only 8.3% (n=71) of the entire survey reported receiving formal training on REDs, with the majority learning this themselves (38.5%, n=329).

Recommendations

There is a lack of funding for assistance on REDs, which is a significant barrier for many individuals seeking help, so education on simple, clinically supported questionnaires like the low energy availability in

females questionnaire (LEAF-Q) and IOC REDs CAT2 could be valuable as individual handouts and help standardise our care (1). However, the LEAF-Q is only specific to females as nearly half of the questions are related to menstruation (51). The LEAF-Q however is a good starting point but should not be used as a diagnostic tool and more a conversation starter for many athletes and their support teams (51, 52). The LEAF-Q was predominantly developed for dancers and endurance athletes, with one study finding in their cohort of 60 professional female football players, that the LEAF-Q was not valid and caution should be taken when using this tool for these types of sporting individuals (53). The REDs CAT2 is more valid overall due to the more rigorous diagnostic methods used with three steps for diagnosis of REDs (5, 54). However, because of these steps it is more costly and has some limitations as it may not be stress tested enough due to the cohort being used (54). Regardless, it is a good tool that can be used and is an excellent place to start with athletes at risk (54).

Many athletes reported a lack of assurance in HCP and coaches, often due to feeling awkward during conversations and struggling to express their feelings. By offering these questionnaires, individuals at risk could benefit from having a more comfortable way to share their concerns, and coaches and HCP could also more easily screen for and review potential risks, helping break down communication barriers and make individuals feel more at ease when discussing sensitive topics. In addition, using an athlete health and readiness checklist could help identify and maintain athletes at their best health and performance and allow coaches and HCP to identify possible factors that could impact the athlete (55). This tool is recommended not as a diagnostic tool as it does not define REDs but merely for helping signpost tools that would be appropriate for HCP and coaches to utilise, making it an excellent introductory resource (55).

As well as increasing education on the importance of a menstrual cycle to increase knowledge, particularly in males. In addition to this recommendation, more training in coaching and healthcare conferences should be provided at the appropriate level to offer up-to-date education on this syndrome, supporting individuals to feel more confident about treatment or onward referral processes.

Limitations

Despite the survey being publicly accessible and promoted on numerous male-focused pages, such as Ironman training and cycling pages, male participation remained lower than females (1:16.2). Consequently, the volume of data collected from male respondents and coaches was insufficient, reducing the ability to generalise the findings when comparing gender knowledge on REDs. The wording or appearance of the survey may have deterred male participants, as REDs is considered a predominantly female issue. Some feedback indicated that individuals were unfamiliar with the topic and did not wish to participate in the survey. With the disproportional groups used, there was a sample size variation within demographics, so generalisations from some groups are invalid, and definitive comparisons cannot be made. Additionally, the sample may be biased due to participants having an interest in this topic and

therefore wanting to participate. The data used was from any participant that answered at least one question in the survey which allowed for as much data as possible to be used and reviewed.

Future studies should investigate why males respond less to surveys about REDs and aim to improve participation rates, especially as males coached most female respondents. Adding tick boxes for common sports (e.g., running, cycling, gym, CrossFit) could streamline analysis, enabling comparisons across sports groups and allowing for more specific help in each category. It should also be investigated whether more weight-dependent sports have differing beliefs or attitudes on REDs symptoms.

Conclusions

The mixed results of this survey highlighted the considerable variation of knowledge within REDs across different demographics. While females and HCP showed higher levels of understanding, the lower scores among athletes and coaches revealed significant gaps in knowledge that require attention. These disparities may stem from personal experiences, cultural backgrounds, and societal influences, all of which shape how individuals perceive and respond to the concept of REDs.

Despite their superior knowledge, HCP still need more support and access to competent referral systems within their settings. This study provides direction for developing tailored educational initiatives to ensure that athletes and coaches receive targeted support. This requires a more integrated approach to improving the support structures for HCP and coaches, enabling them to better address REDs.

Chapter 4: Discussion and Conclusions

Comparative analysis of Chapters 2 and 3

This thesis is comprised of two research manuscripts (Chapters 2 and 3) that investigate the current knowledge of REDs among HCP, coaches, and athletes. Chapter 2 offered a detailed systematic literature review, focusing on management strategies, current education systems and overall knowledge of individuals. The systematic review found that females are generally more educated about REDs than males, and individuals with a history of REDs were more knowledgeable. By synthesising findings from these various cohorts, this chapter provided a collective insight into the strengths and limitations of existing REDs education and management approaches (28, 34, 39). However, the studies were limited by small cohorts and the use of specific groups of individuals, either geographically or through sports. The systematic review lacked diversity, thus reducing its generalisability to the REDs community.

Chapter 3 expanded on the literature with original research based on a questionnaire. It offered a more comprehensive perspective, incorporating broader viewpoints to deliver a globally generalisable analysis. It expanded the discussion by exploring individuals' perceived confidence in their knowledge, ability to identify REDs, and the overall support for managing the condition. Chapter 3 used some key questions discussed in the systematic review but expanded them into a broader demographic, hoping for more widespread findings and better overall analysis that can help improve our current educational systems. It also showed how we can support HCP, coaches, and athletes more regarding REDs. Notably, the findings revealed that athletes often lack adequate support from HCP and coaches, with 49.3% reporting poor support systems or discomfort in discussing potential REDs symptoms like irregular menstruation. This was a higher percentage than what was found in a recent study that only saw a total of 35% of athletes reporting feeling entirely comfortable talking to their coach if they suspected they had REDs, which is perhaps because HCP were not included in this study (56). Regardless, this aligns with the self-reported challenges faced by coaches and HCP, who expressed low confidence in recognising REDs in athletes and navigating appropriate referral pathways within this study and in others (3, 36, 57). These insights underscored a pressing need for targeted training and communication strategies to bridge the gaps in awareness, confidence, and support systems within the sports community.

Many athletes who experience REDs are in sports that promote a particular body image or pressure individuals to be a certain weight. Regardless, disordered eating is still highly prevalent within REDs and is still an excellent indicator to the coach or HCP that the athlete may need further screening if presenting with particular eating habits (38). There are relationships between a diet that is intentionally or unintentionally restrictive and can reduce the ability to intake calories or micronutrients from all food groups, contributing to REDs (10). Sometimes, individuals are unaware they require more calories, and a multidiscipline approach with a dietician or nutritionist would be beneficial; however, sometimes,

disordered eating is intertwined, and these must be approached carefully. REDs and eating disorders do not necessarily go hand in hand, as many believe and using this as a measure if someone has REDs is not advised. There is a misconception, with one paper finding that only 37% of the 161 physicians answered correctly that REDs and a low BMI or weight loss are always associated (58). However, the prevalence of eating disorders in male and female athletes is approximately 20% higher than in non-athletes (59). Chapter 3 reported an overwhelming agreement among all groups that comments on weight cause long-term issues, with the highest percentage coming from males and those over 60 (100%). This reflected how males are potentially pressured less than females to look a certain way, or their sports are less focused on a certain weight. However, the lowest percentage came from the coaches (96%). Even though this percentage was high, it was disappointing that the individuals who were likely to spend much time with athletes and educate them on the importance of weight scored the lowest. Therefore, having a coach or HCP who is understanding and willing to listen to their athlete and be considerate of weight would allow for better reduction of REDs risk, but to also appreciate that athletes who are not underweight can still develop REDs.

When compared, Chapter 3 provided greater depth to this under-researched area by incorporating a larger and more generalisable cohort. It corroborated the finding that females possess better knowledge of REDs than males. Chapter 3 found a lack of current knowledge in both sexes surrounding symptoms to detect REDs in males. Chapter 2 highlighted the lack of support coaches and HCP often feel regarding this issue. In contrast, Chapter 3 expanded on this by revealing that 70% of surveyed coaches and HCP self-reported a lack of support. Early recognition of REDs can positively impact treatment and protect athletes' short- and long-term health. Therefore, having strong support systems for coaches and HCP is paramount (58). Additionally, Chapter 3 provided more profound insights into the challenges these groups face in identifying and supporting individuals with REDs. Both chapters highlighted a significant gap in educational systems, underscoring the need for enhanced training and resources to empower HCP in addressing REDs effectively (24, 28). Chapter 3 also highlighted that although HCP had better overall knowledge, they lacked confidence in their answers, reinforcing that HCP do not get enough education or support when dealing with REDs. Only 8.3% of the total survey respondents had formal training on REDs, showing how poor the current education systems are, with 38.5% of individuals learning this from their research.

Chapter 2 focused more on females and REDs, which is understandable due to the high prevalence; however, Chapter 3 found that REDs is also poorly detected in males. A recent study examining REDs in Malaysian athletes found that males reported a higher percentage of low REDs risk (24.5%) than females, who exhibited a higher rate of medium to high REDs risk (41.2%) (46). Many of the questionnaires designed to screen for REDs are tailored to female-specific issues, such as menstrual irregularities, which do not apply to males. Alongside poor definitions of LEA for males is that males can endure a more extended period of reduced energy than females before showing the more obvious symptoms, such as reporting low

libido or decreased testosterone (49). Interestingly, 88 studies on REDs showed female athletes were more likely to have REDs, with 7,400 females (78%) compared to 2,105 males (22%). In contrast, the 57 studies on training overload and OTS show a different gender distribution, with only 210 females (19%) and 880 males (81%) (50). This makes us question if OTS is more predominant in males or if it is just REDs misdiagnosed, and our awareness overall is poor. The main difference is that REDs involves bone pathology, while OTS does not (50). They are both based on the diagnosis of exclusion and can be difficult to diagnose initially. OTS is often linked to under-fuelling, which indicates LEA/REDs; however, to rule in OTS, you must rule out REDs (50).

Knowledge, attitudes and beliefs

The systematic review did not go into depth on the beliefs or attitudes; however, these parts are also key to understanding how we can improve the current pathways and care. In the survey, beliefs and attitudes surrounding REDs were briefly looked at, but in relation to knowledge. It gave a viewpoint on the individuals, how a small percentage of athletes reported prioritising training over health, and how many did not understand how decreased fuelling contributes to menstrual dysregulation.

The systematic review and survey showed that females were better at identifying REDs than males. The survey also revealed that athletes had the lowest knowledge of the three groups. Interestingly, HCP were the most knowledgeable but noted themselves as the least confident with their answers compared to the other groups. Both the review and survey indicated that HCP and coaches report a lack of support within this area, with the survey showing that many feel unsure about referral pathways and identifying REDs. This was also found in a recent paper, with only 50% of coaches and 13% of athletes were completely confident in their answers regarding REDs (56). However, only the athletes' confidence significantly increased after being educated through a panel and education session, while coaches' confidence remained the same (56).

Athletes also felt coaches and HCP were not equipped to talk about REDs or other hormonal changes, with 49.3% of athletes reporting a lack of support, with many mentioning their coaches’ attitude or behaviour around menstrual cycles, and they felt ignored.

Although it was found that most HCP, coaches, and athletes display positive attitudes regarding REDs, they lacked the necessary knowledge, with 70% of HCP and coaches asking for more support and education. A study looking at awareness and confidence in REDs showed that only 36% of physicians had knowledge of REDs, and only 13% of HCP stated they felt comfortable treating the condition (60). Therefore, better systems and resources must be implemented that are accurate, educational, and at the right level, which can positively impact athletes, coaches and HCP.

Current and future education and practical experience

Currently, funding to see a practitioner who treats REDs is non-existent in New Zealand. As REDs is not an accident, they do not come under any public funding, and waiting to see dieticians on the public health system would be classed as a non-urgent referral, which takes three to six months.

As a physiotherapist working in New Zealand, having competent referral pathways and resources is paramount for reducing an individual's health decline. Cost can pose a considerable barrier when seeking assistance and understanding where to access the best advice can also be difficult, with many confusing posts and discussions on social media. This barrier arises from the absence of public funding in New Zealand and numerous other countries, combined with the lack of consistent early screening protocols that HCP or GPs could implement to identify early LEA symptoms. Individuals could pay several hundred dollars for a dietician, with more specialised dieticians costing $400 and up. This is in addition to any further blood panelling, scans, or potential psychological and physiotherapy appointments. Many individuals do not have the personal funds to address the issue, and as REDs is seen more predominantly in athletes, it may also not be a top priority for the athlete and it may not be brought up to their coach or HCP (10).

To allow for better collaboration between coaches, HCP and REDs specialists, a focus on basic education such as REDs early signs, understanding surveys that show LEA/REDs symptoms, and improving the space for communicating with each other and our athletes should be implemented. Discussing REDs with professionals is crucial; however, even discussing symptoms and educating athletes about why fuelling and recovery are essential at a gym or athlete level is also vital. These small changes should help standardise our care, raise awareness and ensure that athletes needing specialist referrals are identified earlier and more effectively. Improving the overall HCP knowledge around this area also means fewer individuals will need to find the funds to see specialists, and perhaps early diagnosis within our HCP and coaching groups also means individuals wouldn't be as high of a risk of REDs.

The survey found that many athletes felt uncomfortable or dismissed when talking about their menstrual cycle with male coaches and HCP and speaking to male colleagues. Another study indicates that some coaches do not view REDs as a serious issue, while the adverse health effects of long-term LEA on female athlete well-being can be significant (61). This can reflect the poor education and professional development in coaching courses, with many coaches not requiring qualification at lower-level sports. Many athletes reported feeling awkward or unsure in the survey when talking about this to female patients or athletes. This leads us to think about how we can change the narrative within this demographic and provide better resources to the community. Some easier options would be a poster which has easy-to-read information about fuelling and symptoms that should not be ignored, such as menstrual irregularity, decrease in libido, and increased injuries, with contact information for individuals who seek more advice and guidance. Delivering education in various ways allows a larger demographic to be captured and further discussed. There is an undertaking with Netball Smart and ACC SportSmart introducing 'smart health' to

discuss the importance of fuelling and menstrual irregularity to young females. Whilst this is a significant step forward, there is a lack of education for young males in sports. Due to the difficulty in understanding REDs with males and the current knowledge surrounding them, a programme for males would also provide immense benefits.

Another way to increase awareness and knowledge around REDs is to involve this topic more in conferences such as the Sports Medicine New Zealand Conference and smaller branch seminars, the Physiotherapy New Zealand Conference, the New Zealand College of General Practitioners conference, to increase discussion and feedback on what each profession is struggling with and how we can reduce barriers.

Many athletes are more likely to see their GP for amenorrhoea than their physiotherapist or other HCP. It was reported that when presented with a patient with amenorrhoea and training for 15 hours a week, 46.6% of the responding gynaecologists would recommend starting oral contraception (28). There is considerable concern around contraceptives due to their ability to mask menstrual irregularities and the implications this causes to athletes when ignored (62). Therefore, speaking to local GP clinics to ensure they understand REDs and the symptomatology in each sex would be paramount to having a well-rounded and competent level of care. Further research could specifically investigate the perspectives of mental health nurses, therapists, and sports dietitians who work closely with sports teams to identify areas where they would feel more supported and the gaps in understanding that may exist within each team (36).

The survey found that 19% (n=143) of females and 38.6% (n=17) of males were unsure if bone-related issues occurred after three months of menstrual irregularity. The overall knowledge surrounding menstrual health was lacking, especially in athletes. Within many sports and gyms, losing menstrual regularity is almost a badge of honour to show how hard you have pushed your body, and the oral contraceptive pill seems to be prescribed to regulate irregular periods instead of investigating this further (62). Therefore, educating athletes on this would be critical to reducing the risk of further impacting their health. Other factors would include some simple advice on fuelling around training and consuming a pre-exercise meal over fasted training, mainly when the duration and intensity of the training increased, which was greatly important for improving overall performance by enhancing aerobic capacity and cell signalling. (63).

Thesis limitations

With REDs still being a newly researched area encompassing many individuals from various demographics, we found that the systematic review in Chapter 2 needed to be expanded to be more generalisable. Each study analysed in this systematic review was restricted to small cohorts and specific sports. Many factors can impact individuals in each sport, such as training hours and weight requirements, so having just one sport reviewed could not allow the studies to be generalised to the broader population. The survey in Chapter 3 undertook a wider demographic within the research. Still, it lacked certain aspects,

such as a large male cohort and coaches, which reduced the validity of the findings in these cohorts and made comparing them to the other groups challenging. In addition, having a smaller cohort within specific subgroups made it difficult to compare the groups fairly. Following on from this, having a box for common sports would have allowed us to categorise the different sports and coaches better, and this could have given specific trends in sports that are more weight-focused over others and drawn some conclusions with this data. The data from the research was predominantly qualitative, which meant numerical data could not be extracted and easily presented—making this study harder to validate and open to perhaps more bias. Additionally, improving the structure of the survey to enable a more in-depth analysis of gender and group trends would be beneficial, especially given that many females are more likely to have a male coach and many team physicians are male (64). A stronger quantitative data set would have given a more substantial comparative and reliable analysis. However, the qualitative method gave a more in-depth analysis by identifying the hidden needs within our current system.

Recommendations for future studies

Future research could explore why existing education systems are insufficient in supporting these groups and work towards improving access to referral pathways. Given that many athletes are self-coached, beliefs and attitudes were only touched on, and the survey found that many individuals had a lot to say about these systems. If further education and courses were offered to these groups, more analyses on what is required and what individuals want more help and guidance would be incredibly beneficial. It is essential to develop educational resources accessible for current and future generations, considering changes in technology and habits and ensuring they are comprehensible across varying levels of knowledge. Many athletes are self-coached and may lack the same health literacy as an HCP or coach, which makes having appropriate resources fundamental. This will ensure that individuals know where to seek further advice or care and that the provider can offer optimal management.

The chapters in this thesis revealed these factors by compiling current knowledge and providing new insights into improving the existing REDs awareness and management systems. However, future studies should examine male knowledge more and compare different trends within different sports, age, and sex. It is also important to have a more accurate and efficient way to quantify and assess the length of time someone has been in their role and how this may impact their experience and appreciation of REDs (25). Given that a majority of female athletes reported working with male coaches, it is essential to identify the specific knowledge and attitudes of these coaches towards their female athletes. Additionally, having particular data for each sport could allow more specific screening tools to be developed, such as the Dance Specific Energy Availability Questionnaire (DEAQ), which helped screen artistic dancers for REDs risk and made it more suitable for individual sports (65).

The data collected was primarily qualitative. Including additional quantitative data to provide numerical figures such as p-values, standard deviation, and measures of variability for future research could help compare groups and better analyse the data. A recent systematic review (66) also acknowledged the lack of data and high dropout rates in studies and reported that further research surrounding this topic alongside improved methodology would be required to provide a more robust analysis into REDs interventions.

Conclusions

The findings from the literature review of nine studies and the survey of 471 athletes, 29 coaches and 134 HCP highlighted a clear need for enhanced education on REDs. This could be implemented by improving educational resources for coaches and HCP, tailoring content and resources to the level of expertise in the room and educating athletes on a better understanding of their bodies and the importance of the relationship between fuelling, recovery and training.

Appendices

Appendix A – Prospero registration

ID:	Title:	Status:	13/02/2024
CRD42024509394	Systematic literature review of knowledge of RED-S in athletes amongst health care professionals, coaches and athletes.	Registered - Completed	

Appendix B – Supplementary information for Chapter 2 Literature review – CASP

The use of CASP promoted evidence-based decision-making and enhanced the ability to discern each paper's strengths and limitations. The 10 items in the qualitative analysis were: 1) Was there a clear statement of the aims of the research?; 2) Is a qualitative methodology appropriate?; 3) Was the research design appropriate to address the aims of the research?; 4) Was the recruitment strategy appropriate to the aims of the research?; 5) Was the data collected in a way that addressed the research issue?; 6) Has the relationship between the researcher and participants been adequately considered?; 7) Have ethical issues been taken into consideration?; 8) Was the data analysis sufficiently rigorous?; 9) Is there a clear statement of findings?; 10) How valuable is the research?

The one study using a randomised controlled trial was analysed using the CASP framework (15). The 11 items in the analysis were: 1) Did the study address a clearly focused research question?; 2) Was the assignment of participants to interventions randomised? 3) Were all participants who entered the study accounted for at its conclusion? 4) Were the participants 'blind' to intervention they were given? Were the investigators 'blind' to the intervention they were giving to participants? Were the people assessing/analysing outcome/s 'blinded'? 5) Were the study groups similar at the start of the randomised controlled trial? 6) Apart from the experimental intervention, did each study group receive the same level of care? 7) Were the effects of intervention reported comprehensively? 8) Was the precision of the estimate of the intervention or treatment effect reported? 9) Do the benefits of the experimental intervention outweigh the harms and costs? 10) Can the results be applied to your local population/in your context? 11) Would the experimental intervention provide greater value to the people in your care than any of the existing interventions?

Appendix C – Supplementary information for Chapter 3 Survey

Survey questions

Q1 Introduction to survey

Q2 Please select if you are an athlete, coach or healthcare professional.
(If you fit in two or more categories, please select the last box and write what categories)
Healthcare professional
Coach
Athlete (amateur or professional)
I fit into two or more categories - please specify which ones.

Q3 Please state the level at which you compete/coach and/or the type of sport or health profession you are in.
(Please be as specific as possible, e.g., the sport you do - amateur/professional; new-grad/ junior/specialist/post-grad etc).

Q4 The average hours you work/train a week.

Q5 What is your age?
18-25 years old
26-30 years old
31-40 years old
41-50 years old
51-60 years old
60+ years old

Q6 What race/ethnicity best describes you?
New Zealand (Please specify: European, Māori, Pacifica, Asian)
Australian
Canadian
Asian/Pacific Islander
American (Please specify: White/Caucasian; African American, Asian American, Multiple ethnicity)
Hispanic, Latino, or Spanish Origin
British (Please specify: White/Caucasian, Black/Caribbean/African, Asian, Multiple ethnicity
European (Please specify country of origin)
other - please state

Q7 Which country do you live in?
New Zealand
Australia
United States of America
Canada
United Kingdom
Europe - please state country
Other - please state country

Q8 How do you identify?
Female

Male
Non-binary/Third-gender
Prefer not to say

Q9 How long have you currently been in this role/sport?
Over this period, has this role developed? (e.g., - become more specialist, gone from amateur to professional sport)?

Q10 If you are an athlete, what is/has been the gender of your primary coach(es)?
Male
Female
I coach myself
Third-gender/ Non-binary
I am not an athlete

Q11 If you are Coach or Health Professional, what is/has been the gender of your athletes?
Male
Female
Non-binary / third gender
Not applicable

Q12 Have you heard of Relative Energy Deficiency in Sport (RED-S)?
Yes
Maybe - heard of it but unsure what it is
No

Q13 Please state how you learned about RED-S.

Q14 Have you heard of any RED-S screening tools that may be used if you think someone is at risk or showing symptoms?

Q15 Please answer true or false to the below statements.
Males have a higher risk of developing RED-S as compared to females.
True
Equal in both genders
False

Q16 RED-S is relatively rare and not often seen.
True
False

Q17 RED-S and overtraining are essentially the same thing.
True
False

Q18 Prioritising training and performance over long-term health is sometimes necessary and okay if it is only short term.
True
False

Q19 Having an irregular period as a female is often a sign the female is in peak physical condition, and if only short-term, should not require any concern.

True
Not sure
False

Q20 It is normal for females to miss their period when they are active.
True
False

Q21 If you do not consume enough energy (e.g. food) this can contribute to females missing their period.
True
Neither true nor false
False

Q22 Comments and pressure of weight for a sport that focuses on appearance are important and do not cause any long-term problems.
True
False

Q23 RED-S will always involve an eating disorder.
True
Unsure
False

Q24 Low Libido can be associated in males with RED-S.
True
Unsure
False

Q25 Stress fractures (small cracks) occur more often in females who miss their period for 3 or more months than in females who have regular periods.
True
Unsure
False

Q26 Having a specific dietary requirement (e.g. vegan/ vegetarian/ gluten-free) may increase the risk of developing RED-S
True
False
Neither true nor false

Q27 Hormonal contraception (e.g. oral contraceptive pill) should be the main way of treating females with irregular periods.
True
Unsure
False

Q28 When on hormonal contraception (e.g. oral contraceptive pills), females get a period and this indicates the female does not have menstrual irregularity.
True
Unsure
False

Q29 What is the approximate age that peak bone mineral density is reached in females?
12-18 years old
18-29 years old
30-34 years old

Q30 If you are an athlete please tick the athlete box and skip this question.
If you are a coach or healthcare professional please read the case study below.
Case study : A 19-year-old female runner has come to see you after being diagnosed with a tibial stress fracture- what are the 3 key questions you would ask this person before treating or training them?

Q31 Please tick all the relevant boxes that could be associated with RED-S.
Menstrual dysfunction
Increased sprinting ability
Decreased performance
Increased injury risk
Increased muscle strength
Decreased co-ordination
Weight and body composition changes
Negative impact to mental health
Positive impact to mental health
Improved bone strength
Improved endurance performance
Decreased focus
Increased gastrointestinal problems
Sleeping difficulties
Increased irritability
Decreased immunity
Increased cardiac risk

Q32 How confident do you feel in identifying RED-S?
Please select the percentage with 100% being
the most confident and 0 being the least.

Q33 How confident do you feel with your overall answers in this survey?
Please put a percentage of confidence with
100% being the most confident and 0% being
the very least.

Q34 I feel supported as a coach/ health care professional that if I see someone with a RED-S risk I have good referral connections and feel confident in dealing with this.

Q35 I feel as an athlete I am well supported by my coach/training group and feel I am able to discuss my concerns around training and diet with coach/ health professional

Q36 I feel comfortable discussing/asking about menstrual cycles with my coach/health professional or athletes.
Q37 Thank you for partaking in this survey.
If you have any further comments please add them below.

Additional survey results

In response to whether **"REDs will always involve an eating disorder",** 749 females and 44 males answered. A significant majority disagreed, with 73.7% (552) of females and 72.7% (32) of males rejecting the notion. Additionally, 24% (180) of females and 19.6% (10) of males were unsure, while 2.3% (17) of females and 4.5% (2) of males agreed. Among 410 athletes, 235 in multiple groups, 121 HCP, and 25 coaches, athletes had the lowest correct response rate (70.7%, 290), with 26.6% (109) unsure. Coaches had the highest correct response rate (84%, 21) and a high uncertainty rate (16%, 4).

In consideration of whether **"having a specific dietary requirement may increase the risk of developing REDs",** 747 females and 44 males answered. More females (61.7%, 461) than males (56.8%, 25) agreed, while 30.4% (227) of females and 34.1% (15) of males were unsure. Among 407 athletes, 236 in multiple groups, 121 HCP, and 25 coaches, athletes had the lowest correct response rate (57.5%, 234), while HCP had the highest (67.8%, 82).

In reply to whether **"when on hormonal contraception, females get a period, and this indicates the female does not have menstrual irregularity",** 752 females and 44 males answered. A significant majority of females (85.1%, 640) disagreed, compared to a lower percentage of males (56.8%, 25). However, 13% (98) of females and 38.6% (17) of males were unsure. Among 412 athletes, 236 in multiple groups, 121 HCP, and 25 coaches, athletes had the lowest correct response rate (78.6%, 324) with 18.2% (75) unsure, while coaches had the highest correct response rate (92%, 23) with 8% (2) unsure.

In evaluating the question **"What is the approximate age that peak bone mineral density is reached in females?"**, 749 females and 44 males answered. A slightly higher proportion of females (71.8%, 538) than males (65.9%, 29) correctly identified the 18-29 age range. Among 409 athletes, 236 in multiple groups, 121 HCP, and 25 coaches, athletes and HCP had the highest correct response rate (71.9%, 294 and 87 respectively), while coaches had the lowest (64%, 16).

Appendix D – AUTEC ethics

6 May 2024
Patria Hume
Faculty of Health and Environmental Sciences

Dear Patria

Re Ethics Application: 24/117 Assessing knowledge of Relative Energy Deficiency in Sport (RED-S) in health professionals, athletes and coaches.

Thank you for your responses to AUTEC's conditions.

Your ethics application has been approved for three years until 4 May 2027.

Non-Standard Conditions of Approval

1. The revised definition of female could be more simply stated as Assigned Female at Birth.
Non-standard conditions do not need to be submitted to or reviewed by AUTEC unless requested but must be completed before commencing your study.

Standard Conditions of Approval
1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC.
2. All public facing documents must have the AUTEC approval number and be of a high standard of spelling and grammar. Dates on the Information Sheet(s) and Consent Form(s) must be consistent.
3. Any amendments to the project must be approved by AUTEC prior to being implemented.
4. A progress report is due annually on the anniversary of the approval date.
5. A final report is due at the expiration of the approval period, or, upon completion of project.
6. Any serious or adverse events must be reported to AUTEC, this includes unforeseen issues that might affect continued ethical acceptability of the project.
7. AUTEC grants ethical approval only. You are responsible for obtaining management permission for access from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

The application number and title need to be referenced on all correspondence related to this project.

All forms are available online http://www.aut.ac.nz/research/researchethics

For any enquiries, please contact ethics@aut.ac.nz
(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

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