The prevalence of low energy availability risk in New Zealand track athletes

A thesis

presented to

Massey University

In partial fulfilment of requirements

for the degree of:

Masters of Science (MSc)

In

Nutrition and Dietetics

By

Eliot Rhys Fenton

2022

Abstract

Background: Low energy availability (LEA) is a state in which an individual has insufficient energy to maintain and support normal physiological functions. This is often influenced by changes in energy intake (EI) or energy expenditure through exercise (EEE). Low energy availability is the aetiology of the syndrome relative energy deficiency in sports (RED-S) and the female athlete triad (FAT). Together, these models encapsulate the effects upon physiological systems such as menstrual, psychological, haematological, metabolic, and endocrine function, and bone health, to label a few. To date, LEA research predominately focuses on females and endurance sports athletes. There is minimal research on male athletes or high-intensity sports, such as sprinting.

Methods: A total of 24 amateur-elite athletes (males, *n* =10; females, *n* =14) aged 16–35 years participated in this cross-sectional study. All participants competed in at least one athletic track event (100m, 200m, 400m, 800m, 1500m, 3000m, 5000m, steeplechase and hurdles) in the 2019/20 or 2020/2021 athletic seasons. The risk assessment for LEA was determined online through a validated screening tool (low energy availability questionnaire (LEAF-Q)) for females and an arrangement of three validate questionnaires (Sexual desire inventory, Androgen deficiency in males and gastrointestinal questions from LEAF-Q) aimed at assessing key LEA measures for males such as sexual desire, mood and gastrointestinal function. These LEA-assessing questionnaires were a part of a larger online questionnaire to identify key risk factors and physiological outcomes of LEA (e.g., sleep behaviour and qualities, eating disorder risk, exercise dependence).

Results: This study determined 57% (*n* = 8) of female participants and 50% (*n* = 5) of male participants were at risk of LEA. This study observed that females at risk of LEA had significantly poorer sleep behaviours(p <0.05), higher depression score and eating disorder examination (EDE) global score than those females not at risk of LEA. Results showed trends that males not at risk of LEA were more likely to have better sleep scores ($d = -0.87$). In the EDE males not at risk of LEA had lower eating concern ($d = -0.86$), body shape concern ($d = -0.95$), weight concern ($d = -0.94$) and risk of global eating disorder examination (*d* = *-0.8*). In the exercise dependence scale males not at risk of LEA showed a higher tolerance (*d* = *1.1*), continuance (*d* = *0.88*), lack of control (*d* = *0.65*) and lower intentions of effect (*d* = - *0.94*). Whereas female athletes not at risk of LEA tended to be less likely to display LEA associated physiological and psychological risk factors such as within EDE assessment showing lower eating restraint (*d* = *-1.1)*, eating concern (*d* = - *0.71)* and shape concern (*d* =*-1.2)*. Within the exercise dependence scale females not at risk of LEA had a higher tolerance of exercise (*d* = *0.74)*, time of exercise (*d* = *0.6)* and intentions (*d* = *0.71)*.

Conclusions: This pilot study highlights that among this sample of amateur-elite athletes, 54% were at risk of LEA (57% female, 50% male). Therefore, there is a need to further investigate and quantify LEA measures within male and female athletes involved in sprinting. This study also identifies that the aetiology of LEA for athletes is complex due to multiple psychological influences identified within the environment of participants.

Acknowledgements

"It always seems impossible until it's done"

- *Nelson Mandela*

I would like to take this moment to acknowledge those who have supported me through this journey. I am grateful of having the opportunity to work with Dr Claire Badenhorst and Dr Wendy O'Brien throughout this thesis research. They have been inspirations and mentors to me, not just through the duration of my masters but since my undergraduate degree at Massey University. Their passion for science and ability to advance the learning of others and topics within the world of science has given me the drive to succeed and make an impact with my future endeavours of work. You have taught me a lot about myself, grown my interest and love for science and have facilitated the growth of my academia skills. Thank you.

This journey has not been easy, nor should it be. I felt challenged and at times defeated, though writing these final acknowledgments I can reflect on the journey it has been. If you would have told my teachers in high school that I would completing a Master of Science, we would have laughed together.

To my family (especially my mum) thank you for keeping tabs, and trying to understand my journey and decision making. Though at times our ideologies may not align I am grateful for your continued support. Rachael, your tenacity, ambition, and drive have helped me renew my own ambitions and you have helped me fill my cup this past year.

"Ehara taku toa i te toa takitahi, engari he toa takitini."
- *My success should not be bestowed onto me alone,*
as it was not individual success but success of a collective.

Table of Contents

List of abbreviations

ANOVA	Analysis of variance
ADAM	Androgen deficiency in aging males
AN	Anorexia Nervosa
ASBQ	Athlete sleep behaviour questionnaire
BMD	Bone mineral density
BN	Bulimia nervosa
DE	Disordered eating
DIT	Dietary induced thermogensis
ED	Eating disorder
EDE	Eating disorder examination
EDNOS	Eating disorders not otherwise specified
EA	Energy availability
EEE	Energy expenditure through exercise
EI	Energy intake
EDS	Exercise dependence scale
FAT	Female athlete triad
FFM	Free fat mass
GLP-1	Glucagon – like peptide – 1
HPG	Hypothalamic-pituitary-gonadal-axis
IGF-1	Insulin like growth factor – 1
ID	Iron deficiency
IDA	Iron deficiency anaemia
LEAF-Q	Low energy availability female questionnaire
LBM	Lean body mass
LH	Leutinizing hormone

LEA	Low energy availability
NZ	New Zealand
NEAT	Non-exercise activity thermogensis
PPY	Peptide YY
PPE	Preparticipation physical evaluation
POMS	Profile of mood state
RED-S	Relative energy deficiecny in sports
RMR	Resting metabolic rate
SDI	Sexual desire inventory
SD	Standard deviation
T_3	Triiodothyronine

List of tables

Chapter 1: Introduction

Energy availability (EA) is a relatively new concept in physiology and nutrition which has continued to be developed since the early 90s. Energy availability defines the energy that is available to maintain normal physiological function after the subtraction of energy expenditure through exercise (EEE) from energy intake (EI) relative to lean body mass (LBM) (kcal/kg LBM/day) (Areta et al., 2020a; Loucks, 2020). Energy availability can occur due to variance in an individual's EI which can occur intentionally/unintentionally by restricting EI through eating disorders (ED), disordered eating (DE) behaviours (Sundgot-Borgen & Torstveit, 2010), psychological stress in relation to performance or body image (Heather et al., 2021), lack of nutritional knowledge (Condo et al., 2019; Heikkilä et al., 2018; Logue et al., 2020), low energy density diets (Melin et al., 2015; Reed et al., 2011; Reed et al., 2014) and financial insecurity (Burke et al., 2018). Another influence that alters an individual's EA is the variance of EEE. This includes the increased outputs due to exercise dependence/compulsive exercise, or due to the high volumes demanded by sports where energy expenditure exceeds EI. Variance in EEE can be driven by negative perceptions of body image and has been linked to female ED patients (Bratland-Sanda et al., 2011; Cook et al., 2016) and performance outcomes, and can be associated with specific sports like cycling, long-distance running and triathlon (Torstveit et al., 2019). When there is a balance between EI and EEE in relativeness to an individual's LBM, they will have optimal or high energy availability (males >45 kcal/kg/free fat mass (FFM); females >40 kcal/kg/FFM). Athletes who do not meet EI requirements or have unattainable EEE may not have sufficient energy to support normal physiological function. When EA is not optimal, this is labelled as low energy availability (LEA). Through laboratory observations of an LEA state, there are suggested EA cut-offs of subclinical LEA (males 30–40 kcal/kg/FFM; females 30–45 kcal/kg FFM) and clinical LEA (males and females <30 kcal/kg FFM) (Melin et al., 2019).

To date, the majority of research regarding LEA has focused on female athletes, as a result of investigating the female athlete triad (FAT). The basis of the FAT is that it focuses on the triad relationship between women's bone mineral density, menstrual function and EA (with or without ED/DE) (Nattiv et al., 2007). With the development of EA and an LEA state in females, it was also looked at within endurance sports, which is associated with a higher probability of experiencing negative LEA associated physiological consequences (due to the high demand of EEE) (Loucks, 2004). There has since been evidence to suggest symptoms associated with an LEA state including reduced leptin, insulin, triiodothyronine (T3), fasting blood glucose, luteinizing hormone (LH), cortisol, insulin-like growth factor (IGF-1) and a reduction in bone formation (Wasserfurth et al., 2020). As a result, the changes in these hormones and blood markers may cause acute changes such as reduced resting metabolic rate (RMR), decreased rate of weight loss, poor concentration, memory, reaction time, poor training and exercise performance and recovery, menstrual irregulates in females and increased injury rates (Areta et al., 2020a; Mountjoy et al., 2014). Long-term effects of an LEA state may present as amenorrhea (cessation of menses and ovulation (Marcus et al., 2001)) in females, osteoporosis, reduced muscle strength and a reduction in testosterone levels in males (Wasserfurth et al., 2020)

In comparison, there is limited research in male athletic populations. Research has also pursued the creation of a male triad-like equivalent (De Souza, Koltun, et al., 2019a, 2019b). This aims to show recognition that at the centre of an LEA state, there are potential negative physiological consequences in male athletes. This includes the likes of reproductive suppression (e.g., reduced testosterone, sperm quality and libido) and metabolic suppression (e.g., reduced leptin, IGF-1, insulin) leading to lower bone turnover and increased risk of fractures (De Souza, Koltun, et al., 2019a, 2019b). This has been recognized from earlier work that highlighted an exercise-hypogonadal male condition in which males experienced reduced RMR and total testosterone levels due to chronic endurance exercise training (Hackney & Hackney, 2005). It is suggested that male athletes at risk of a male triad-like syndrome are those that participate in sports that emphasise leanness (e.g., combat sports, jockeys, endurance sports) and are more likely to experience nutritional deficits, and reduction in sex hormones and bone health (Tenforde et al., 2016)

International Olympic Committee (IOC) proposed a new model 'relative energy deficiency in sports'

(RED-S) in 2014 to account for the wider physiological effects of LEA in both male and female athletes (e.g., cardiovascular, psychological, growth and development, hematological, metabolic) (Mountjoy et al., 2014). Secondly, it aimed to describe the changes that may occur in males that have not been represented in previous LEA research (Mountjoy et al., 2014). To date, there are still many areas that remain to be classified and investigated to identify the causal relationship between LEA and physiological outcomes (Areta et al., 2020a).

Controlled laboratory studies can influence the EEE and EI of participants and help advance the knowledge of EA and its outcomes (Areta et al., 2020a; Melin et al., 2019). However, the use of controlled laboratory studies does not represent an athlete's environmental pressures, where athletes will experience different influencing factors that drive EEE and EI (e.g., nutritional knowledge, perceptions of body image and performance, financial insecurity). Therefore, studies that require athletes to self-report EEE and EI under the supervision of a health professional can help guide the understanding of LEA risk factors. In addition, the use of self-reported EEE and EI is an effective method to manage an athlete's health at all levels of sport. The previously mentioned research and body of work around LEA has often focused on endurance and aesthetic sports. Typically, athletes in endurance sports experience large training volumes and high energy expenditures and are therefore more likely to present with LEA because of inadequate nutritional knowledge or DE behaviours (Torstveit et al., 2019). In comparison to endurance sports, athletes may appear to benefit from lighter body weights or demonstrate an increase in performance when there is a reduction in body weight in sports such as running, cycling, rowing, and horse racing (Burke et al., 2018). Though, athletes in the mentioned sports may demonstrate DE behaviours such as restrictive eating, fasting, skipping meals, diet pills and laxatives to achieve a reduction in body size for competition (Burke et al., 2018). It has been recognized that psychological perceptions of body image (e.g., athletic and societal expectations), drive for thinness to influence aesthetic and performance, exercise dependence and poor nutritional knowledge may all contribute to LEA occurring in male and female athletes (Gibbs et al., 2011; Heather et al., 2021; Wasserfurth et al., 2020). However, the length of time an athlete needs to be in an LEA state before noticeable declines in physiological health or presentation for assistance from health professionals is unknown.

There are limited investigations into the relationship between LEA and high-intensity sports, such as sprinting (Sygo et al., 2018), and overall, there is a concern for those athletes' well-being, health, and performance. The concern lies in the matter that athletes, coaches, family members, and support staff may not be aware of how quickly the body responds to severe states of LEA. Furthermore, there are more concerns for athletes that compete in sports where there is limited LEA understanding, such as sprinting. Therefore, a lack of understanding in sports such as sprinting may lead to those athletes limiting their opportunity of optimizing their physiological function, recovery, and sports performance. Moreover, the limited information and understanding of LEA and the associated risks within sprinting populations show a need to establish an understanding of the prevalence of RED-S symptoms and severity of LEA in New Zealand (NZ) track athletes (Sygo et al., 2018). There are several concerns that may predisposed track athletes to RED-S, including behaviours such as intentional alterations in their body mass or composition, drive for thinness, appetite changes, low-density diets, time constraints, ED/DE behaviours and performance outcomes (e.g., power to weight ratios) (Melin et al., 2019). To date, there is one study that has looked specifically at the prevalence of LEA in elite female track athletes. At the end of the 5-month training camp, 54% of the 13-cohort presented with at least one primary LEA indicator (e.g., amenorrhea, low bone mineral density, RMR ≤29kcal/kg fat-free mass and LEAF-Q score ≥8) and one secondary LEA indicator (e.g., low IGF-1, ferritin <25 µg/L and fasting insulin <20 pmol/L); deeming them to be at risk of LEA (Sygo et al., 2018). The previous research in elite female Canadian sprinters identifies that they are at risk of an LEA state. Therefore, it shows that there is a need to understand whether there is a similarly associated prevalence of LEA in pre-elite athletes such as New Zealand male and female amateur-elite sprinters.

1.1 Aims, objectives and hypothesis

The overall aim of this research is a pilot study to identify the prevalence of RED-S symptoms and associated severity of LEA in female and male track athletes in New Zealand, along with the following objectives:

1. To determine the prevalence of physiological, psychological and associated symptoms of LEA amongst track athletes within New Zealand using a series of validated questionnaires.
2. To assess if the risk of LEA in track athletes affected their health, wellbeing, and performance.

We hypothesize that at least 50% of sprinters will be at risk of LEA, with a higher risk of LEA in female sprinters than in male sprint athletes. Female and male athletes at risk of LEA will have had more illness diagnoses, bone stress injuries and iron deficiency diagnoses in the last 12 months. Athletes at risk of LEA will have a poorer sleep score, and higher fatigue and depression scores. Finally, athletes with a higher risk of LEA will be at higher risk of ED and exercise dependence.

Chapter 2: Review of Literature

2.1 Introduction

Energy is needed for multiple physiological processes such as resting metabolic rate (RMR), dietary-induced thermogenesis (DIT), non-exercise activity thermogenesis (NEAT) and energy expended through exercise (EEE). The concept of energy availability (EA) is used to define the energy remaining from energy ingested as food that has not been utilised for EEE, and therefore, is considered the energy that is available for other physiological functions (e.g., RMR, DIT) (Loucks et al., 2011; Loucks, 2004). Energy availability can be estimated by subtracting energy intake (EI) from EEE and then dividing the sum by lean body mass (LBM) (Areta et al., 2020a; Loucks, 2020). Previously research has developed thresholds for EA based on sex, as shown in Table 1 (Melin et al., 2019). The EA thresholds suggest that individuals could be in a state of high EA (>40-45 kcal/kg LBM/day), where an individual has an abundance of energy available to be utilised for EEE, recovery, health and wellbeing. On the other end, an athlete can have limited energy available to support EEE, health and wellbeing and as such, would be considered to be in a state of low energy availability (LEA) (<30kcal/kg LBM/day). Low energy availability occurs when an individual's EEE is greater than their EI. Symptoms associated with an LEA state include reduced leptin, insulin, triiodothyronine (T3), fasting blood glucose, luteinizing hormone (LH), cortisol, and IGF-1, and a reduction in bone formation (Wasserfurth et al., 2020). As a result, the changes of hormones may cause acute changes such as reduced RMR, reduced weight loss, poor concentration, memory, and reaction time, poor training and exercise performance and recovery, menstrual irregulates and increased injury rates (Areta et al., 2020a; Mountjoy et al., 2014). Long-term effects of an LEA state may present as amenorrhea, osteoporosis, reduced muscle strength and a reduction in testosterone levels (Wasserfurth et al., 2020). Despite the array of negative health and performance effects of an LEA state, it has been identified that some Olympic sporting federations are not providing the needed education around LEA to athletes and coaches (Mountjoy et al., 2018). Education focused on nutrition, and strategies to maintain optimal EA, are important in the prevention, intervention and management of LEA in athletes (Melin et al., 2019).

Athletes should be provided with tools and education on nutritional intake and support for EEE and healthy physiological functioning. It is also important that athletes, coaches and health professionals can identify risk factors, psychological impairment and physiological disturbances associated with inadequate EA. Coaches and health professionals have a role in supporting athletes to optimise EI and understand nutritional food groups to benefit performance outcomes (Loucks, 2004, 2007; Wade & Jones, 2004). Potential streams of education could aid athletes in maintaining appropriate adequate EA levels throughout season cycles (e.g., pre, post and during competition) in their sporting career.

The majority of research around LEA has focused on female and endurance athletes (Mountjoy et al., 2014). Research in male athletes and high-intensity sports such as sprinting is limited, however, results from current research would suggest that it is necessary (Burke et al., 2018). A study that focused on 13 elite female track athletes showed that 31% and 54% of sprinting populations were at risk of LEA in pre-season and post the indoor track season, respectively. Here researchers assessed LEA risk though primary indicators such as amenorrhea, low bone density, hormone levels, RMR, and LEAF-Q. As well as secondary indicators such as fasting blood glucose, IGF-1, blood pressure, and ferritin (Sygo et al., 2018). The findings of the research may be due to the intensity and volume of pre-season training (increases in EEE) and the reduction of EI due to psychological influences (Heather et al., 2021; Sygo et al., 2018; Wasserfurth et al., 2020), suppressed appetite after training (McCarthy et al., 2020) from changes in appetite regulatory hormones (e.g., ghrelin, PPY, GLP-1) (Howe et al., 2016; Larson-Meyer et al., 2012), low-density diets (Melin et al., 2015; Reed et al., 2011; Reed et al., 2014) and limited nutritional knowledge (Condo et al., 2019; Heikkilä et al., 2018; Logue et al., 2020). Therefore, research in athletic groups at risk of LEA should be cognizant of the potential range of causal factors of LEA and account for them appropriately in their research design.

Table 1: Threshold of energy availability established by controlled research in which there were noted physiological consequences

EA states	Females	Males
High EA	>40 kcal/kg LBM/day	>45 kcal/kg LBM/day
Optimal EA	>40 kcal/kg LBM/day	>45 kcal/kg LBM/day
Subclinical LEA	30–40 kcal/kg LBM/day	30–45 kcal/kg LBM/day
Clinical LEA	<30 kcal/kg LBM/day	<30 kcal/kg LBM/day

(Melin, Heikura, Tenforde, & Mountjoy, 2019).

2.2 Low energy availability

Relative energy deficiency in sport (RED-S) syndrome was defined by the International Olympic Committee (IOC) in 2014. The syndrome RED-S expands the concept and physiological impacts of the female athlete triad (FAT). The female athlete triad is defined as a continuum involving the interrelationship of energy availability (with or without ED being present) and disturbances in menstrual function and bone mineral density (BMD) (Nattiv et al., 2007). Most of the research investigating the effects of chronic LEA on adverse health implications has been focused on females, due to the early recognition of a link between LEA, performance and overall health in women (Nattiv et al., 2007). However, the newly defined RED-S syndrome summarises an array of physiological function impairments such as metabolic rate, menstrual function, cardiovascular health, protein synthesis, psychology and immunity (Mountjoy et al., 2014) in both males and females. The primary aetiology of RED-S symptoms is a state of LEA in both male and female athletes (Mountjoy et al., 2014). Low energy availability has been noted in high prevalence within sports that manipulate weight to maximise power to weight ratios, aesthetics, or for weight required categories (Burke et al., 2018; Wasserfurth et al., 2020).

The adverse health and physiological effects of LEA within males have only recently been studied in relation to RED-S since its inception in 2014 (Mountjoy et al., 2014), to explain physiological implications in both biological sexes. A male athlete triad was proposed in 2005 aligning with the exercise-hypogonadal male condition linking reproductive endocrine dysfunction and physiological impairments such as low testosterone in exercising men when in a state of LEA for a prolonged period of time (Hackney & Hackney, 2005). There is still a need to investigate the pathophysiology of male athletes and their risk of LEA, as there are still many unknowns in this area (Areta et al., 2020a; Mountjoy et al., 2018). Recently, research has shown that LEA may not be limited to just male athletes competing in endurance sports, but also males competing in sports that focus on weight classes, power to weight ratio, or aesthetics (Burke et al., 2018), however, the depth of research in these male sports is still fairly limited. In addition, with the research of RED-S being defined less than 10 years ago (Mountjoy et al., 2014) and reviewed in less than five years (Mountjoy et al., 2018) there are still many areas of unknowns including, the influence of severity, duration and frequency of LEA in males and females, the difference in symptoms presentation between males and females, the difference in risk and causal effects between males and females, to name a few.

2.3 Risk factors of LEA/RED-S

A substantial amount of research has suggested that LEA is influenced by psychological risk factors leading to research focusing on ED and DE within male and female athletes. Athletes are at an increased risk of dieting, DE and ED behaviours, and even more so for elite athletes (Sundgot-Borgen & Torstveit, 2010). The pathology of psychological factors may be influenced by body image dissatisfaction, misinformed nutritional or sporting practices that attempt to manipulate weight for aesthetic, performance-related outcomes, miss information around LEA consequences and knowledge deficits (Condo et al., 2019; Heikkilä et al., 2018; Logue et al., 2020; Sundgot-Borgen & Torstveit, 2010). Risk factors of DE behaviours can therefore be accentuated by athletes within sports that have an emphasis on weight, leanness or aesthetics for both men and women (Burke et al., 2018; Mountjoy et al., 2018; Sundgot-Borgen & Torstveit, 2010). An example of this could be dietary changes for an individual wanting to maximise power to weight ratios or making weight classes (Burke et al., 2018; Wasserfurth et al., 2020). Athletes such as cyclists can be at risk of LEA due to the high energy demands from EEE but also the culture within the sport. Cyclists aim to achieve low body mass to obtain higher power ratios, but this may be obtained through unsafe nutritional practices or DE-like practices (Olds et al., 1995; Viner et al., 2015). Manipulating weight is considered an art form for combat sports athletes, and the financial reward of the sports is at risk if the athlete's weight requirements are not met before an event (Burke et al., 2018). A high prevalence of DE and ED is associated with combat sports athletes when making weight (Brugh et al., 2001; Rouveix et al., 2007). Rowers in open weight classes may manipulate weight so that the boat will sit higher in the water to optimise hydrodynamics. Therefore, rowers may undertake energy restricting practices to reduce or maintain weight despite high EEE (Burke et al., 2018). In addition, energy restricting practices may be more prevalent amongst weight classed (lightweight) rowers (maximal weight for females and males are 59 kg and 72.5 kg, respectively) (Vinther et al., 2006; Vinther et al., 2008). Synchronised swimming is a sport that emphasises lean aesthetics (Robertson & Mountjoy, 2018). Collegiate synchronised swimmers were identified as having dissatisfaction over their body image (Ferrand, 2007). A study comparing eating attitudes for ED's of swimmers, water polo players and synchronised swimmers, saw synchronised swimmers were the most at risk of EDs (Douka, 2008).

It is important to acknowledge that LEA can occur without ED or DE, and can be due to inadequate nutritional knowledge, limited understanding of the consequences of LEA (Condo et al., 2019; Heikkilä et al., 2018; Logue et al., 2020) and the suppression of appetite post-exercise on appetite-related hormones (Howe et al., 2016; Larson-Meyer et al., 2012). However, it appears that the risks of ED and DE practices stem from perceived societal expectations, such as athletes feeling insecure about their body image and that it does not fit either athletic or societal perceived norms (Heather et al., 2021; Sundgot-Borgen & Torstveit, 2010; Wasserfurth et al., 2020). Moreover, an individual can create perceived expectations upon themselves (e.g., conforming to heteronormative appearances, performance expectations) which may be influenced by their home and training environment (e.g., social media, coaches, peers, family members) (Heather et al., 2021; Wasserfurth et al., 2020).

In New Zealand, 15% of elite female athletes self-reported DE behaviours stemming from dissatisfaction with their body image (Heather et al., 2021). Approximately 54% believed that they had to meet the perceived physical pressures of feminine normativity (Heather et al., 2021) or need to have an 'athletic' body (Wasserfurth et al., 2020). As social media perpetuates the societal norms of traditional heterosexuality, athletes may feel their body adaptions from high-intensity sports are not seen as 'feminine'(Wasserfurth et al., 2020). Elite females in New Zealand felt pressure from social media (80%), themselves (77%), and the general public (54%) to have a certain physical appearance (Heather et al., 2021). Unintentional and intentional LEA states in athletes can occur when they face barriers such as a lack of knowledge on meeting EEE via EI, financial hardship and team sporting cultures that promote negative behaviours to reduce body weight for performance outcomes (Burke et al., 2018; Heaney et al., 2008). Research has identified that females were more susceptible to ED and LEA than males (Sundgot-Borgen & Torstveit, 2010). Comparisons are hard to draw between sexes due to the limited amount of research available in regards to male athletes (Wasserfurth et al., 2020).

High-intensity sports are in a position in which weight reduction can increase performance outcomes (Sundgot-Borgen & Torstveit, 2010). Alongside performance outcomes, males may be predisposed to ED behaviours triggered by comments around body weight or shape and performance (Sundgot-Borgen & Torstveit, 2010). These behaviours can be maintained if the athlete feels satisfaction from performance or positive reinforcement from peers, family members and coaches (Sundgot-Borgen & Torstveit, 2010). Research on male athletes such as jockeys, cyclists and combat athletes, also shows that males may face social pressures, and have body image issues (Burke et al., 2018). An athlete's sporting culture may perpetuate the ideology of negative connotations towards body shape through practices of maintaining unhealthy weight, poor weight cyclic management and compulsive exercise tendencies (Burke et al., 2018). Males, like females, may be unable to meet high EEE demands through current or habitual EI. Causes leading to males being unable to meet EEE demands could be compulsive exercise or exercise dependency behaviours leading to very high EEE, which may not be accounted for in their diets (Bratland-Sanda et al., 2019; Dittmer et al., 2018; Torstveit et al., 2019).

Exercise dependence behaviours unintentionally puts individuals at risk of RED-S symptoms leading to an LEA state because of very high EEE (Lichtenstein et al., 2015). The psychological aspect of exercise dependence stems from trying to prevent drastic self-perpetuated health consequences (e.g.

self-image of being healthy or leading an active lifestyle, off-set binging, reducing purging, gaining weight) and distorted beliefs of exercise (e.g. earn their meal, shape control, weight control, reduced guilt, irritability and distress) (Bratland-Sanda et al., 2019; Dittmer et al., 2018). Previous research in females compared 46 longstanding ED patients with 51 non-clinical controls, found that female ED patients had significantly higher exercise dependence (Bratland-Sanda et al., 2011). The study also found that the main reason for higher exercise dependency scores was the need to regulate negative health effects through vigorous rather than moderate activity (Bratland-Sanda et al., 2011). Research into 53 male endurance athletes (cyclists, triathletes, and long-distance runners) observed that 23 (43%) had low exercise dependence in comparison to 30 (57%) male athletes with high exercise dependence (Torstveit et al., 2019). The research found that those with higher exercise dependence did not match their EI to their EEE, increasing their risk of being in a state of LEA. Furthermore, it was found that male athletes with higher exercise dependence had higher eating disorder examination (EDE) scores (Torstveit et al., 2019). The effect of this research suggests that there is a relationship between exercise dependence and eating behaviour in both males and females. There is a proposed link between exercise dependence and the drive for thinness in males that may be due to the desire of achieving an 'ideal' physical appearance based on societal norms. Exercise dependence behaviours should be investigated further to address the exercise paradox and impact upon the psychological system that contributes to RED-S in male and female athletes (Bratland-Sanda et al., 2019; Torstveit et al., 2019; Wasserfurth et al., 2020).

Research needs to identify the psychological pressures individuals feel to inform appropriate health screening tools that assist in identifying early risk factors for LEA. The current tools to assess an athlete's risk of psychological pressures may be too confronting and challenging for athletes to discuss openly with observers/interviewers to draw any conclusions. In their defence, individuals at risk of LEA (due to their behaviours or attitudes) may hide it from interviewers or others due to social stigma (Sundgot-Borgen & Torstveit, 2010). Research shows that there needs to be more support and understanding around the causes of psychological stress for athletes with and without LEA (Drew et al., 2018; Heather et al., 2021; Sundgot-Borgen & Torstveit, 2010; Wasserfurth et al., 2020). Examples of beneficial support for athletes include forms of education to help understand the body's physiological adaption to sport-specific training. Sport-specific education can also help advance performance outcomes and build relationships between coaches, health professionals and families. The relationships in an athletes' support network are important due to the judgement they may face from interactions within their environment (e.g., parents, peers, family members). This may include passing comments on topics such as body image. Support should be offered to athletes when there is psychological distress, and options of education should be provided to create a conversation of body normality in sports to help overcome entrenched sporting ideology on these issues. Overall, support and education would help reduce the risk factors of LEA and mitigate the outcome of negative physiological and psychological effects of RED-S.

2.4 Physiological effects of RED-S

The RED-S model was established through developing research of FAT from the American College of Sports Medicine in 2007. The underlying aetiology of the triad was recognised as EA, causing declines in bone health and menstrual function (Mountjoy et al., 2014; Nattiv et al., 2007). The introduction of RED-S further elaborates on the physiological impacts on the human body that have been observed through research predominantly within females and more recently within males as a result of an LEA state (Mountjoy et al., 2014).

Within the endocrine system, the hypothalamic-pituitary-gonadal-axis (HPG) is affected by an LEA state in both short-term (Loucks et al., 1994b; Loucks & Thuma, 2003; Loucks & Verdun, 1998) and long-term circumstances (Beitins et al., 1991; Bullen et al., 1985; Lieberman et al., 2018; Williams et al., 2015). The impact upon the HPG is linked to reduced fertility and menstrual dysfunction (Fahrenholtz et al., 2018; Melin et al., 2019) in females. This has been suggested to impact health and performance due to the influence of the HPG on the relationship of bone density, haematology status, muscle development, and immunology (Ackerman et al., 2019; Mountjoy et al., 2018). Among females, luteinizing hormone (LH) pulsatility and frequency are reduced due to LEA, when their EA threshold is less than 30kcal/kg LBM/d, subsequently reducing the production of oestrogen (Beitins et al., 1991;

Bullen et al., 1985; Lieberman et al., 2018; Loucks et al., 1994b; Loucks & Thuma, 2003; Loucks & Verdun, 1998; Williams et al., 2015) and progesterone (Areta et al., 2020a; Elliott-Sale et al., 2018). Within males, LEA has resulted in the reduction of free testosterone (Gomez-Merino et al., 2002; Hackney & Lane, 2018; Heikura et al., 2018; Koehler et al., 2016; Kojima et al., 2020) and an increase in the amount of the hormone globin binding proteins, reducing the bioavailability of testosterone (Dolan et al., 2012). Currently, there are inconsistencies within the research of the underlying mechanisms of testosterone and endocrine dysfunction (Elliott-Sale et al., 2018; Koehler et al., 2016). The male reproductive system has been suggested to require less energy to maintain normal functioning (Bronson, 1985), meaning that the male HPG axis is potentially more resistant to the negative endocrine impacts of LEA compared to females (Koehler et al., 2016). Males may need to experience a lower or more severe threshold of LEA than females to experience disruption in the HPG axis, a finding that is presented in prior research and defined in Table 1 (Fagerberg, 2018).

Low energy availability has also been shown to result in the downregulation of the hypothalamic-pituitary-thyroid (HPT) axis, with subsequent reductions in triiodothyronine (T_3), a hormone considered important for growth and metabolism (Elliott-Sale et al., 2018). Reduced triiodothyronine is associated with reduced resting metabolic rate (RMR) (Loucks et al., 1992) in females (Loucks & Callister, 1993; Loucks & Heath, 1994a; Loucks et al., 1994b; Loucks et al., 1992; Loucks et al., 2006; Loucks & Thuma, 2003; Loucks & Verdun, 1998; Papageorgiou et al., 2018; Papageorgiou et al., 2017) and in males who present with low testosterone (Heikura et al., 2018). Females have been shown to have reduced RMR during long-term energy deficiency (Redman et al., 2009). Research in 1000 females found that those with LEA were three times more likely to suffer metabolic issues (Ackerman et al., 2019). The overall implications of lowered RMR for both males and females may include reductions in the overall efficiency and effectiveness of some organs and tissues (e.g., muscle, heart, brain), as well as a decreased rate of weight loss (Areta et al., 2020a; Koehler et al., 2016). This may result in exacerbating the state of LEA in these athletes and may contribute to a more severe presentation of RED-S symptoms.

The hormone leptin is associated with energy status, the regulation of food intake and body weight (Areta et al., 2020a). Leptin is considered to be a prominent marker of LEA in females, with reductions observed in an LEA state. In a study of 11 women, significant differences in leptin levels (µg/L) were observed between an LEA state of 15 kcal/kg LBM/d (-217.1 ± 113.0 µg/L) for 5 days when compared to a control group of 45 kcal/kg LBM/d (-118.3 ± 119.0 µg/L) (Papageorgiou et al., 2017). Another study recorded significant differences between leptin levels (ng/ml) of 60 females in a control EA group of 45 kcal/kg LBM/d (8.8 ± 0.7) and LEA group of 30 kcal/kg LBM (-3.0 ± 0.7) (Loucks & Thuma, 2003). There is limited research on the effects of leptin in male populations, however, in six exercising males, there were significant decreases in leptin levels when comparing post-exercise levels between LEA and EA balanced controls. Post-exercise leptin levels of the two separate controlled protocols of LEA (15 kcal/kg LBM/d – 0.72 ± 0.15 ng/ml; 15 kcal/kg LBM/d + exercise – 0.70 ± 0.19 ng/ml) were different when compared to the two energy balanced conditions (40 kcal/kg LBM/d – 1.46 ± 0.33 ng/ml; 40 kcal/kg LBM/d + exercise – 1.36 ± 0.26 ng/ml) (Koehler et al., 2016). Another study, investigating 11 males, reported no significant differences in leptin levels between EA controls (45 kcal/kg LBM/d; 158.9 ± 219.7 µg/L) and those in an LEA state (15 kcal/kg LBM/d; 26.7 ± 331.1 µg/L) (Papageorgiou et al., 2017). The reduction in leptin is linked to the suppression of key endocrine axes, which is important as it correlates with changes in hormones. The changes include growth hormone and thyroid hormones, which are known to be other physiological disturbances from an LEA state (Elliott-Sale et al., 2018; Koehler et al., 2016).

Stimulation of the pituitary gland produces growth hormone (GH) stimulating the liver to produce insulin growth like factor-1 (IGF-1). Insulin growth like factor-1 and GH provide an indication of the body's response to anabolic factors (anabolic resistance and association with bone loss during states of LEA) (De Souza & Williams, 2004; Loucks & Thuma, 2003; Papageorgiou et al., 2017; Tritos & Klibanski, 2016; Williams et al., 2015) in both men and women (Murphy & Koehler, 2020). Low energy availability is associated with anabolic resistance disrupting the GH and IGF-1 feedback loop. The disruption of these hormones sees an increase in GH and a reduction of IGF-1 levels (Areta et al., 2020a; Elliott-Sale et al., 2018; Kojima et al., 2020; Loucks & Heath, 1994a; Loucks et al., 2006; Loucks &

Thuma, 2003; Loucks & Verdun, 1998; Murphy & Koehler, 2020; Papageorgiou et al., 2018; Papageorgiou et al., 2017). Research in male and female weightlifters aged 19 – 30 years demonstrated the effects of anabolic resistance in short-term caloric restriction (Murphy & Koehler, 2020). Participants underwent three different EA states for three days at a time. There were two conditions of 15kcal/kg/ LBM/d, one with post carbohydrate feeding and another with post protein feeding. The third condition was a control of 40kcal/kg LBM/d (Murphy & Koehler, 2020). The findings reported that anabolic resistance reduces the benefits of resistance exercise such as building muscle mass or bone mineral density (Murphy & Koehler, 2020). This is important for athletic populations because muscle mass and bone density influence training, performance, and injury outcomes.

Frequently, in athletes presenting with LEA, muscle strength and glycogen stores are reduced (Mountjoy et al., 2018), a result likely due to myofibrillar protein synthesis reduction (Areta et al., 2014) as well low carbohydrate availability within the diet (Areta et al., 2020a; Ishibashi et al., 2020; Kojima et al., 2020). The associated weight loss with LEA can be due to a reduction in FFM, fat loss, electrolyte abnormalities and dehydration. This can lead to the reduction of muscular ability (strength) causing implications of reduced performance for individuals (Logue et al., 2018). Research with 10 competitive endurance cyclists (6 male and 4 female) observed that 70% of cyclists experienced LEA across their season. It was observed that low carbohydrate intake (3.9g/kg/d) in addition to low EI were the main contributors to the chronic LEA state (Viner et al., 2015). Similarly, research in 19 female division 1 football players noted that in 5 players who consumed <30kcal/kg LBM, they also did not achieve the American College of Sports Medicine carbohydrate recommendations (6-10g/kg) (Reed et al., 2014). Research in 21 jockeys noted that 71% restricted their energy intake. Further analysis showed that not only was the average daily EI deemed insufficient to maintain daily metabolic processes, but, the average carbohydrate consumption was below the recommendations for the athletes (Dolan et al., 2012). This cumulative research in various athlete cohorts would suggest low intake of carbohydrate within sports can be associated with the increased risk association with an LEA state.

Athletes are at an increased risk of illness when they are in a state of LEA (Mountjoy et al., 2018). Low energy availability is suggested to be one of the risk factors for upper respiratory infections in athletes (Walsh, 2018). It is worth noting that, in research that has assessed LEA and illness incidence, athletes who reported illness within the last 12 months also had higher perceived stress levels (Drew et al., 2017). Therefore, illness incidence is likely to be multifactorial and influenced by LEA and psychological stress (Drew et al., 2018; Drew et al., 2017).

Research to date has increased our understanding of the impacts of an LEA state on the physiological system and the subsequent symptoms of RED-S. The available research highlights the need to explore the impacts of LEA in male athletes and those within high-intensity sports rather than just endurance sports. Psychological factors are also noted as a risk factor of LEA and RED-S, which needs to be considered when working with male and female athletes (Mountjoy et al., 2018; Mountjoy et al., 2014).

2.5 Psychological effects of RED-S

The athlete's psychological state has shown to be bi-directional and is affected by a LEA state but it is also considered to be an aetiological risk factor (Mountjoy et al., 2018). An athlete may face psychological or societal pressures where they feel the need to manipulate their body weight or shape to meet societal norms of body image. This pressure may manifest from social media, self-judgement, and the judgement/comments/feedback of people within the athlete's home and training environment (e.g., coaches, parents, friends and teammates) (Heather et al., 2021; Wasserfurth et al., 2020). The increased risk of negative psychological outcomes, such as increased risk of depressive traits, reduced cognitive function, and social insecurities, is shown to be greater in individuals with a drive for thinness, menstrual dysfunction, EDs and DE (Bomba et al., 2014; Bomba et al., 2007; M. J. De Souza et al., 2007; Marcus et al., 2001). Depressive traits, anxiety and poor mental health have been shown to negatively impact mood, sporting capacity and sleep (Drew et al., 2018; Drew et al., 2017). This is important because it shows how psychological pressure is seen in athletes such as body dissatisfaction (Heather et al., 2021), DE, ED and drive for thinness (Mary Jane De Souza et al., 2007; Marcus et al., 2001; Sundgot-Borgen & Torstveit, 2010) can further influence negative physiological outcomes of an

LEA state.

Another aspect of psychological factors associated with LEA is the fear of negative consequences from the lack of exercise (Bratland-Sanda et al., 2019; Dittmer et al., 2018). Low energy availability in men may be driven or created by compulsive disorders, such as unhealthy relationships with exercise or dependency on exercise to achieve self-imposed pressures of body image (Bratland-Sanda et al., 2019; Burke et al., 2018; Dittmer et al., 2018; Torstveit et al., 2019; Wasserfurth et al., 2020). Research in healthy male endurance cyclists found that the exercise dependence scores were similar to that of inpatient females with ED (Torstveit et al., 2019). Key observations within the study were higher scores of tolerance and time of exercise compared to female ED patients, meaning that exercise was prioritised to obtain physical outcomes (Torstveit et al., 2019). A relationship between exercise dependence and DE/ED behaviours and symptoms was noted, in which they can occur independently, or be an underlying risk factor to each other (Torstveit et al., 2019). However, the underlying issue for males is that they face similar feelings of dissatisfaction regarding body shape or performance outcomes as females. Therefore, male and female athletes are driven to make decisions from psychological pressure in which they want to look a certain way or that they believe it will result in superior performance outcomes. An example of this was in endurance athletes trying to manipulate weight to power ratios (Torstveit et al., 2019). Psychological pressures observed in females may come from social media, coaches, family or peers (Heather et al., 2021), and research suggests these risk factors are just as influential for men (Wasserfurth et al., 2020). Overall, those within the athlete’s environment (e.g., coaches and family members) need to understand driving factors that impact an athlete’s decision making regarding their sport, training, health, and wellbeing. External supporters are all part of the solution to identifying LEA and RED-S early (Mountjoy et al., 2018).

2.6 Screening LEA and RED-S risk

It is challenging to diagnose and screen LEA accurately. A mixture of screening tools that focus on the causes and risk factors of LEA could identify possible individuals at risk (Mountjoy et al., 2014). The difficulty remains in insufficient screening tools that assess males' risk of LEA, compared to women with the example of the LEAF-Q (Mountjoy et al., 2018).

Due to no male equivalent of the LEAF-Q at the time of writing this review being available, it was noted that validated questionnaires such as the ADAM (androgen Deficiency in Aging Men) and the SDI (Sexual Desire Inventory) questionnaire could be a useful for screening males at risk of an LEA. These questionnaires could be used in conjunction with other related measures such as testosterone levels. The male SDI questionnaire is a clinically validated questionnaire that is used in the assessment of the strength of sexual desire and behaviour. Sexual desire is referred to as libido, sexual drive, sexual motivation, sexual interest, and sexual appetite (Spector et al., 1996). The ADAM questionnaire is important in assessing androgen deficiency in males, is non-invasive and has high sensitivity. It has been validated against collected and measured testosterone levels in males (Morley et al., 2000). Surveys, such as these, could be used with other screening tools (e.g., self-monitoring of EI and EEE) to review LEA risk in male athletes.

Self-reporting EI has errors that may occur due to misreporting (both under and over reporting) (Burrows, 2019); however, it remains one of the most effective in-field methods for assessing an individual's EI (Mountjoy et al., 2018). A review of 59 studies comparing estimated EI vs total energy expenditure measured by the doubly labelled water, observed that majority of studies observed significant underreporting of EI (Burrows, 2019). The method with the lowest misreporting in EI is the use of 24 hour food/dietary recalls (Burrows, 2019). The lower rates of misreporting are due to the provision of prompts that can reduce the recall bias. In addition, the recent and short timeframe to recall also improves the quality of the EI records (Burrows, 2019). This highlights the importance in the role of health professionals such as dietitians to collect accurate EI information. Therefore, multiple methods of measuring dietary intake could be useful to use when collecting dietary intake of athletes. The role of dietitians and other health professionals, such as psychiatrists, can support individuals' relationships and behaviours with food and provide strategies to meet EEE (Mountjoy et al., 2014). Energy availability requires EI, EEE and anthropometric data. Despite self-reporting issues with EI and EEE, this remains the most valid for 'in field measurements' of EA assessment. Also, athletes appear to be able to self-report anthropometric data quite accurately (Nikolaidis & Knechtle, 2020; Seijo et al., 2018). The use of anthropometry in athletes has been seen as valuable for performance outcomes such as race time and injury prevalence (Nikolaidis & Knechtle, 2020). Research shows that the use of BMI (height and weight) may be more frequently monitored in athletic populations such as marathon runners (Nikolaidis & Knechtle, 2020). Research suggests that the under-estimation in weight (especially in females) and an overestimation in height (especially in males) of self-reported anthropometric data and the differences relative to measured weight and height are negligible (Seijo et al., 2018). Therefore, this could suggest that sprinting populations may be aware of their anthropometrics in accordance with performance outcomes, injury prevention and overall risk of LEA.

Tools for measuring and gathering data on EEE, EI and body composition continue to be developed and the information is quantified to establish EA. In consideration of the developing theories on the casual links of LEA (Areta et al., 2020a), the continuum of RED-S and the impact upon the physiological system (Mountjoy et al., 2018), there is limited research on additional factors within recreational and amateur-elite athletes. There are still large errors within the collection tools such as relying on self-reporting of EI and EEE, which affect EA estimates. In contrast, specific laboratory control may provide more quantified outcomes, but do not represent an athlete's environment. Within a dynamic sporting environment, social-cultural factors need to be assessed thoroughly to establish links with key identified risk factors of LEA. This is important to help identify tools and educational areas which can reduce and prevent long-term behaviours, attitudes and skewed beliefs that may contribute to LEA incidence in athletes.

2.7 Athlete support for risk of low energy availability

Understanding the risk factors of LEA is important for athletes, coaches, support staff, family members and peers to reduce the risk of negative physiological consequences associated with RED-S. Athletes need to understand the different energy requirements of their body such as growth, muscle development, DIT, NEAT and RMR before adding in EEE. Despite small participant groups in existing research and the ethical concerns over invoking long periods of an LEA state, further research is still required to establish a causal link between LEA and physiological outcomes to better understand the risk factors for LEA (Areta et al., 2020a).

Support staff and medical professionals should work together to identify signs of negative psychological impacts, reduced performance, and declines in sleep behaviours. Social stigmas can cause individuals to hide behaviours such as DE practices of restricting energy intake or compulsive exercise dependence (Cook & Hausenblas, 2008; Heather et al., 2021; Kuikman et al., 2021; Torstveit et al., 2019; Wasserfurth et al., 2020). These behaviours may be driven by psychological influences such as perception of one's body shape, the comparison to peers or social media and performance (Mountjoy et al., 2018). This shows the importance of psychological support from staff and health professionals within athletic environments, especially within athletic populations with associated LEA risk behaviours. Furthermore, it also questions the need for education for athletes and those within an athlete's support network (e.g., individuals, coaches, family members and peers) to understand associated behaviours that may put them at risk of LEA and RED-S. Medical staff, support staff and health professionals are critical in providing education around LEA/RED-S risk factors. They can also contribute to creating an environment inclusive of all those involved in the athlete's care and that everyone can confidently discuss psychological or physiological issues that they feel are pertinent. Ultimately it also comes down to the athlete being able to feel supported and understand the risk factors associated with LEA and RED-S.

There have been noticeable physiological changes which effect an athlete's performance such as, increased risk of injury, fatigue, increased illness, changes in the female menstrual cycle or decreased appetite (Areta et al., 2020a; Mountjoy et al., 2018). There has been limited research looking at the specific relationship between an LEA state and mood (e.g., depression and irritability). The most recent findings between mood and an LEA state were observed in a study of 1000 female athletes where those with LEA had a greater prevalence of depression and irritability (Ackerman et al., 2019). Another study assessed LEA and depression in 317 athletes (male and female) reporting that 17% had depressive tendencies (Drew et al., 2018). Further research has been completed in 219 New Zealand athletes in which 11% had reported a diagnoses of depression or anxiety (Heather et al., 2021). Irritability and depression in individuals have also been associated with other psychological aspects of LEA such as ED/DE and exercise dependence (Dittmer et al., 2018; Nattiv et al., 2007; Torstveit et al., 2019).

Another limited aspect of LEA research is the effects on sleep. Research has shown that a lack of sleep is negatively linked to overall well-being (Grandner, 2017). There has been one study that have looked at the association between sleep and an LEA state (Drew et al., 2018). In 132 male and female Olympic athletes, 85 females ~40% scored >8 in the LEAF-Q, suggesting they were at risk of LEA. Within this study, 49% of male and females provided Pittsburgh Sleep Quality Index (assessing sleep quality, latency, duration, efficiency and disturbances) scores >5, the clinical threshold for poor sleep (Drew et al., 2018). The prevalence of the poor sleep scores was suggested to be associated with gastrointestinal issues disrupting sleep. Gastrointestinal issues are also linked to a LEA state (Mountjoy et al., 2018). In 67 elite gymnasts, 77.6% presented with poor sleep quality (assessed by the Pittsburgh Sleep Quality Index). It was also found that the average carbohydrate intake of the gymnasts was below the recommendations of the American Dietetic Association. Along with this, 37.3% of the gymnasts had EA below 45kcal/kg LBM/day and 44.8% had an EA below 30kcal/kg LBM/day. This study demonstrates the influence of an LEA state on an individual’s sleep (Mountjoy et al., 2018). It also indicates there needs to be more research on the effect of LEA, sleep, mood, cognitive function and performance (Fullagar et al., 2015).

Equally important is the dissemination of information regarding LEA and RED-S aetiology to health professionals, coaches, management, and athletes. This is important because having a greater understanding of the wider associated negative consequences of a LEA state can raise awareness for athletes. Furthermore, increased knowledge of issues outside of eating, exercise and menstrual cycles can also help guide support staff to evaluate athletes’ health to mitigate the risk of a LEA state occurring. There is a need of growing conversations between coaches, and support staff with athletes around their health to prevent greater the risk of an LEA state and RED-S occurring at any time of an athlete's training calendar (Sygo et al., 2018). The issue, however, remains in the ability to adapt research outside of a controlled laboratory environment that provides an athlete with the best level of care that supports performance outcomes.

2.8 Risk factors of LEA in track athletes

The current risk of LEA in track athletes is unknown as it is still an area under investigation to determine the prevalence. This is because the majority of research within LEA and RED-S has predominantly been within female athletes and those participating in endurance, aesthetic and weight focused sports (Areta et al., 2020a; Mountjoy et al., 2018). In comparison to endurance sports, sprinting has been associated with a lower EEE due to its relatively short duration. Therefore, the understanding of LEA and what potential impacts it has upon males and females in high-intensity sports such as sprinting is limited. Research comparing endurance runners and sprinters showed that sprinters are less associated with risk factors of LEA (Ikedo et al., 2016). The researchers observed a significantly higher bone mineral density (total bone minus the head: sprinters 1.023 g/cm^2, endurance runners 0.981 g/cm^2) and less menstrual dysfunction (sprinters 23.8%, endurance runners 56.3%, $p < 0.01$) in sprinters when compared to endurance runners (Ikedo et al., 2016). This could be due to the sprinter's high magnitude loading phases and lower exercise volumes. Similar results were found in female elite sprinters in which the risk of LEA was assessed, with 23% of participants reporting menstrual abnormalities through the assessment by a LEAF-Q ≥4 score for the menstrual function-specific questions (Sygo et al., 2018).

Risk factors of LEA associated with sprinters are psychological dilemmas (female athletes in particular) where ED or DE behaviours are driven by environmental or sporting factors (Heather et al., 2021; Sundgot-Borgen & Torstveit, 2010). Sprinters may undertake dietary manipulation or restriction in which the aim is to reduce their body weight to either maximise power to weight ratios or for aesthetic reasons (Mountjoy et al., 2018; Sundgot-Borgen & Torstveit, 2010). Aesthetic reasons for sprinters to manipulate weight and energy intake could be due to the change of performance wear within the sport itself (e.g., the popularity of sportswear, reduction of total materials in sporting garments). In research that investigated NZ female elite athletes, 9% of total athletes participated in athletics (Heather et al., 2021). In this wider study population, 73% of athletes believed there was pressure to have a specific physical appearance when participating in elite sports (Heather et al., 2021). Of those that participated in the study, 15% reported engagement in DE practices (e.g. dietary restriction, training on rest days, purging, vomiting, laxatives) (Heather et al., 2021).

In conjunction with the psychological pressures of body image and the relationship to eating behaviours, is the relationship between exercise and appetite regulation after exercise. Research has shown that despite the intensity of exercise, males and females participating in activity will see a change in appetite-regulating hormones post-exercise (e.g., decrease in ghrelin, increase PPY and GLP-1) (Howe et al., 2016). Research in 15 highly trained endurance female athletes underwent a moderate (60% VO_2 max) and high (85% VO_2 max) intensity bout of exercise analysing appetite hormones before, during and after. There was a significant difference between hormones before and immediately after exercise showing appetite suppression. However, there was no significant difference in appetite suppression between the exercise intensities (Howe et al., 2016). Similarly, research comparing runners' and walkers' appetite hormones pre- and post-exercise showed a larger reduction in appetite in running than walking, post-exercise (Larson-Meyer et al., 2012). This is important for sprinting athletes (male and female), as high-intensity exercise can suppress appetite post-exercise. This is a risk factor leading to an LEA state because it may cause an athlete to not refuel during recovery, reducing EI overall, and also reducing the body adaptions targeted by training sessions.

2.9 Research on low energy availability in track athletes

A recent study investigated the prevalence of LEA and key indicators within elite female sprinters (Sygo et al., 2018). The study had a small sample size of 13 female participants taking place following an Olympic year at the beginning of a pre-season training block. Of the female athletes, 31% presented with at least one primary indicator of LEA such as amenorrhea), low bone mineral density, RMR ≤29kcal/kg fat-free mass and LEAF-Q score ≥8 and a secondary indicator such as low IGF-1, ferritin

<25 μg/L and fasting insulin <20pmol/L; deeming them to be at risk of LEA. By the end of a five-month training block, 54% of participants presented with one primary and secondary risk factor for LEA (Sygo et al., 2018). The study analysed blood markers to look for any alterations pre- and post-training block. There were 10 athletes of the 13 not using exogenous hormonal contraceptives during the study. It was observed that of the 10 athletes, 6 (60%) displayed low sex hormones in post-training blood analysis. However, these findings were not reflected in the LEAF-Q answers with only one athlete reporting menstrual disturbances. It could also suggest that athletes may not be aware of what subtle changes can occur to a menstrual cycle and assume the loss of a menstrual cycle as the main 'disturbance' to the menstrual cycle. Previous stress fractures were reported amongst athletes, but no difference was observed in BMD between pre and post the training block, aligning with the idea that sprinters' training volumes and intensity may provide a protective element for bones (Warden et al., 2021). It is also important to understand that this study was limited by sample size (as is most of the previous LEA research), which adds to the limitations of drawing casual links between LEA and physiological disturbances (Areta et al., 2020a).

Current research on LEA physiological outcomes could be relevant factors to consider when reviewing sprinters' health and performance. Possible negative outcomes include low RMR, increased risk of injury (e.g., stress fractures), reduced myofibrillar protein synthesis, reduced muscle adaption from training specific to sprinting, decreased concentration, mood, poor sleep behaviours, and the disruption to hormones (e.g., leptin, oestrogen, testosterone, IGF-1, GH). There is also research that suggests athletes in a state of LEA may have reduced neuromuscular reaction time, which would impact a sprinter's performance (Tornberg et al., 2017). Overall, this suggests a vast array of potential negative effects, both health and performance-based, in this cohort of athletes if they are at risk of LEA. Researchers suggested that the risk of a LEA state for sprinters may occur due to unintentional or intentional reduction of EI with motives to prevent weight gain (Sygo et al., 2018). This is important because it suggests that alternative factors such as restricting EI to maintain weight can put athletes at risk of LEA and RED-S even before pre-season training starts (Sygo et al., 2018).

The current gap within research of LEA is the identification of the prevalence of risk within male and female amateur-elite track athletes. Recent research has highlighted that elite female track athletes are at risk of multiple factors associated with LEA, therefore, highlighting this group as being potentially at risk of LEA (Sygo et al., 2018). However, the research on 13 elite female track athlete's did not addresses the additional risk factors for LEA outside a track athlete's training load such as sleep, mood, psychological stress related to body image, performance outcomes, inability to fit societal norms, and DE behaviours (Drew et al., 2018; Heather et al., 2021; Sundgot-Borgen & Torstveit, 2010; Wasserfurth et al., 2020). Moreover, the risk factors associated with RED-S and LEA are multifactorial with dependency (e.g., ED associated with high exercise dependence) and also independent of each other (Areta et al., 2020a; Mountjoy et al., 2018). This is important because it shows the need for research to identify the role of nutritional knowledge, attitudes, beliefs and eating behaviours of track athletes to identify possible psychological reasons that could contribute to ED's, DE and exercise dependence. Investigating underlying psychological tendencies could help provide insight on how to improve the overall health, performance and retention of recreational and amateur-elite track athletes. Therefore, the use of questionnaires in the study aimed to assess areas of limited research such as sleep and mood. Therefore, this reasoning highlights the importance of more research in sprinting athletes as these pressures can alter their desire of training and eating, influencing their behaviours and risk of LEA.

2.10 Conclusion

The negative impact upon the physiological systems that stem from RED-S is likely due to the presence of a prolonged or severe state of LEA. Low energy availability risk factors can present independently due to unintentional or intentional behaviours but are also multifactorial through an element of dependency (e.g., ED associated with high exercise dependence). The aetiology of LEA is therefore multifactorial for individuals making it difficult to pinpoint specific relationships (Mountjoy et al., 2018). Some individuals may not be able to meet their EEE through their daily EI, because of barriers such as limited nutritional knowledge or financial support contributing to a progressive state of LEA (Burke et al., 2018). Psychological factors such as intentional restriction of EI to reduce weight to meet sporting expectations of aesthetics, weight classes or for performance improvements may also contribute to an LEA state (Burke et al., 2018; Sundgot-Borgen & Torstveit, 2010). Individuals also face socio-cultural pressures from themselves, coaches, peers and social media (Heather et al., 2021; Wasserfurth et al., 2020) influencing athletes' beliefs, and nutritional behaviours. Therefore, athletes should receive education that aims to create an understanding and empowerment to reduce social pressures and focuses on how to appropriately meet EEE requirements. On the contrary, there is limited knowledge that informs theories of the social influences of sport, nutritional beliefs and body image affecting recreational and track athletes. Therefore, research should aim to investigate the risk factors contributing to a state of LEA in amateur-elite and recreational track athletes. This should be inclusive of psychological factors that contribute to negative performance outcomes such as eating behaviours, training behaviours, nutritional knowledge, relationships with food, personal beliefs of health, mental health, team culture, sporting culture, mood, sleep, body image, other people, and social media.

Chapter 3: The prevalence of low energy availability risk in New Zealand track athletes

Abstract

Background: Low energy availability (LEA) is a state in which an individual has insufficient energy to maintain and support normal physiological function. This is often influenced by changes in energy intake (EI) or energy expenditure through exercise (EEE). Low energy availability is the aetiology of the syndrome relative energy deficiency in sports (RED-S) and the female athlete triad (FAT). To date research of LEA has predominately focused on females and endurance sports athletes, with minimal research into high-intensity sports such as sprinting, or male athletes.

Objectives: This study aimed to investigate the prevalence of risk of LEA in New Zealand male and female amateur-elite track athletes during the 2020/21 athletic season. It also sought to determine the prevalence of physiological and psychological symptoms of LEA.

Methods: Twenty-four participants (males, n = 10; females, n = 14) aged 16 – 35 years were recruited to participate in this study. The protocol required participants to complete an online survey comprised of validated questionnaires (perceived physical evaluation, athlete sleep behaviour questionnaire, profile of moods, low energy availability female questionnaire, sexual desire inventory, androgen deficiency in aging males, eating disorder examination (EDE) and exercise dependence scale.

Results: This study determined that 57% (n = 8) of female participants and 50% (n = 5) of male participants were at risk of LEA. This study observed that females at risk of LEA had significantly poorer sleep behaviours (p <0.05), higher depression score and EDE global score than those females not at risk of LEA. Results showed trends that males not at risk of LEA were more likely to have better sleep scores (d = - *0.87*). Within EDE males not at risk of LEA were more likely to have a lower eating concern (d = *-0.86*), shape concern (d = - *0.95*), weight concern (d = *-0.94*) and risk of global eating disorder examination (d = *-0.8*). Trends in exercise dependence scale showed males not at risk of LEA were more likely to have a higher tolerance (d = *1.1*), continuance (d = *0.88*), lack of control (d = *0.65*)

and lower intentions of effect (*d = - 0.94*)

In contrast, female athletes not at risk of LEA tended to be less likely to display LEA associated physiological and psychological risk factors such as within the EDE categories lower eating restraint (*d = -1.1)*, eating concern (*d = -0.71)* and shape concern (*d = -1.2)*. Furthermore, in the exercise dependence females not at risk of LEA showed trends that they were more likely to have higher tolerance (*d = 0.74)*, time of exercise (*d = 0.6*) and intentions (*d = 0.71*).

Conclusions: This cross-sectional study highlights that amateur-elite high-intensity sports athletes are at risk of LEA. Therefore, there is a need to further investigate to quantify LEA measures within male and female athletes involved in sprinting. This study also identifies that the aetiology of LEA for athletes is complex due to multiple psychological influences from within their environment.

3.1 Introduction

Energy availability (EA) is used to describe the remaining energy from food that has not been utilised for exercise and is available to support the functioning of various body systems (Loucks et al., 2011; Loucks, 2004). Varying states of EA can occur when there is an imbalance of either exercise, energy intake or both. Low energy availability occurs when an individual's energy intake (EI) is insufficient to meet their energy expenditure through exercise (EEE) and normal physiological function inclusive of non-exercise activity thermogenesis (NEAT), resting metabolic rate (RMR), and dietary-induced thermogenesis (DIT) (Loucks et al., 2011). Relative energy deficiency in sport (RED-S) is a syndrome that categorizes physiological impairment such as metabolic rate, menstrual function, cardiovascular health, protein synthesis, psychology and immunity (Mountjoy et al., 2014). To date, research has sought to clarify the physiological outcomes of RED-S within females and the impacts upon the female physiological system (De Souza, Koltun, Strock, et al., 2019; De Souza, Koltun, et al., 2019a; Dipla et al., 2020; Nattiv et al., 2007). The current knowledge of male athletes is fairly limited. More recently, research has investigated the possible risk factors of LEA that may result in RED-S, within both male and female athlete population groups (De Souza, Koltun, et al., 2019b; Dipla et al., 2020; Goodwin et al., 2014; Hackney & Lane, 2018; Hackney et al., 2017; Koehler et al., 2016; Kojima et al., 2020; Lane et al., 2019; Papageorgiou et al., 2017; Tenforde et al., 2016; Viner et al., 2015).

It has been noted that RED-S is not a syndrome exclusive to female endurance athletes as was previously believed (Mountjoy et al., 2014). RED-S can affect recreational through to elite athletes, males and females, and sports that have either large training volumes or are low in volume but high in intensity (e.g. sprinting) (Areta et al., 2020a; Burke et al., 2018; Heather et al., 2021; Mountjoy et al., 2018; Wasserfurth et al., 2020). Research has been most prevalent in endurance sports (e.g. distance running, cycling, triathlon), therefore more research in high-intensity sports (e.g. sprinting, athletics, rowing, combat sports) is required (Burke et al., 2018; Sundgot-Borgen & Torstveit, 2010; Sygo et al., 2018).

Current knowledge shows that athletes presenting with eating disorders (ED) or disordered eating (DE) patterns are at a higher risk of being in a physiological state of LEA (Mountjoy et al., 2018). Previous research also shows that females are more susceptible to ED and DE than males (Torstveit et al., 2008). Over the last decade, the prevalence of athletes and non-athletes at risk of ED and DE appears to have increased (Torstveit et al., 2008). The increased prevalence of ED has been due to the growing knowledge and expansion of how eating behaviours are categorised (Sundgot-Borgen & Torstveit, 2010; Torstveit et al., 2008). Category-specific clinical ED's such as anorexia nervosa (AN) and bulimia nervosa (BN) do not capture some negative eating behaviours. Therefore, later research has recognised the inclusion of DE and eating disorders not otherwise specified (EDNOS) (Sundgot-Borgen & Torstveit, 2010; Torstveit et al., 2008). This has meant an increased awareness of negative eating behaviours that is not limited to strict clinical definitions. Research has shown that 20% of female and 8% of male athletes were at risk of and met criteria for ED compared to 9% of female and 0.5% of male non-athletes (Sundgot-Borgen & Torstveit, 2004). Comparisons between female elite athletes and non-athlete controls also identified that 32.8% and 21.4%, respectively, had clinical ED's (Torstveit et al., 2008). Therefore, it is important to understand the reasons why athletes, in particular, participate in negative eating behaviours that cause detriment to their health, well-being and performance.

Sports and/or athletes vulnerable to a physiological state of LEA are those that prioritise power to weight ratios, have weight classes categories or have an aesthetic element. Athletes may progress to a state of LEA unintentionally, due to a drastic increase in their exercise intensity or volume, or failure to increase food intake that matches training demands (Torstveit et al., 2019). Therefore, sports that have high energy outputs or limited feeding windows (e.g., endurance running, endurance cycling, rowing) (Burke et al., 2018; Heather et al., 2021) may have a higher risk of athletes being in an LEA state/RED-S. External factors such as team culture, other athletes/teammates/peers, the coach's own beliefs on body composition, training and nutritional intake, misinformation, and perceptions of the 'ideal' athletic body impact an athlete's food intake (Wasserfurth et al., 2020). The combination of external factors contributes to the growing pressures an individual athlete faces. Also, athletes may perceive external pressures of societal expectations of needing to conform to feminine or masculine figures. Societal expectations are a contributing psychological factor to an LEA state (Burke et al., 2018). This suggests that it is important to research the psychological impact that athletes face regarding body image, weight, ED/DE, and the effect upon their overall exercise performance as a result of being in a state of LEA.

Previously, research has given little attention to sports such as sprinting, as the training volumes of the sport were considered too low to create an LEA state (Areta et al., 2020a; Mountjoy et al., 2018). However, one recent study assessed the prevalence of LEA indicators within female elite sprint athletes over a 5-week pre-season training camp (Sygo et al., 2018). At the beginning of a pre-season training block, 31% of the assessed female athletes were deemed at risk of LEA and post 5-week training block approximately 54% were at risk of LEA. In addition, 24% reported menstrual abnormalities and 46% demonstrated low sex hormones. Based on these results, there is an apparent need for additional research on the prevalence and impacts of an LEA state within sprint focused athletes (Sygo et al., 2018).

The objective of this study was to determine the prevalence of physiological, psychological and associated symptoms of LEA amongst track athletes within New Zealand using a series of validated questionnaires. The secondary objective was to assess if the risk of LEA in track athletes affected their health (e.g., menstruation, injury, illness, ED, DE) wellbeing (e.g., sleep behaviour, mood, exercise dependence) and performance (e.g., track times, muscle strength, muscle endurance). This study hypothesizes that at least 50% of sprinters will be at risk of LEA, with a higher risk of LEA in female sprinters than male sprint athletes. Female and male athletes at risk of LEA will have more frequent illness diagnoses, bone stress injuries and iron deficiency diagnoses in the last 12 months. Athletes at risk of LEA will have a poor sleep score, and higher fatigue and depression scores. Finally, athletes with a higher risk of LEA will have higher risks of ED and exercise dependence.

3.2 Methods

Participants

Male and female athletes aged 16 – 35 years were eligible to participate in this pilot study if they had competed in the New Zealand 2019/20 or 2020/21 athletics season in events of 100m, 200m, 400m, 800m, 1500m, 3000m, 5000m, steeplechase and hurdles. Participants were invited between October 2020 and March 2021 through word of mouth, social media platforms (i.e., Facebook, Instagram), athletic newsletters, training groups/clubs, and athletic communities including High-Performance New Zealand and Athletics New Zealand. There were 35 participants contacted via email (participants were given study information and the link to survey), from the athletes contacted 24 completed the survey. All participants were provided with and encouraged to read an information sheet that detailed all processes involved in the study. The participants were sent an online survey link, including a screening questionnaire to determine if they met the inclusion criteria for the study. If the inclusion criteria were met, participants were then directed to an online form to confirm consent before commencing the full online survey. Ethics approval for this study was obtained through the Massey University Human Ethics Committee Southern A, Application 20/37.

Previous research in RED-S has varied in sample sizes in cross-sectional studies, collecting data from 10-1000 participants (Ackerman et al., 2019; Civil et al., 2019; Holtzman et al., 2019; Mathisen et al., 2020; Torstveit et al., 2019). Research in this field that collects physiological, nutrition and physical data in sports science are typically collected in small sample sizes (n = 10-12). Research that has focused specifically on sprinters, data has only been collected from 13 female athletes (Sygo et al., 2018). This research aimed for a sample size of 36 participants generated by a G power analysis for the difference in mean from one sample case with a p value of <0.05 and 90% probability. Therefore, the aim was to recruit a minimum of 40 athletes (20 males and 20 females). Participant recruitment was impacted by COVID-19 and lockdown regulations greatly impacting total participant numbers.

Procedure

Data were collected via an online questionnaire which consisted of a series of previously validated questionnaires using Qualtrics^{XM} Survey Software (Qualtrics, Provo, UT). The online questionnaire contained 168 items for males and 171 items for females and was estimated to take approximately 15-20 minutes. Participant characteristics were collected, including, age, sex, supplementation use, smoking status, ethnicity and level (e.g., recreational, national, international) and distance/event of competition.

The online questionnaire included a series of validated questionnaires (six for the females and nine for males). These were to assess general health, bone health, injury risk, sleep behaviour, mood, LEA risk in females and LEA associated symptoms in males assessed via sexual desire, ED's and exercise dependence.

Preparticipation physical evaluation, cardiovascular and bone health

The preparticipation physical evaluation (PPE) is designed as a screening tool to assess injuries, illnesses and other factors in athletes and is used to promote health and safety during exercise participation (American Academy of Family Physicians et al., 2019). The PPE has previously been used as a screening tool for risk factors and conditions associated with the female athlete triad (American Academy of Family Physicians et al., 2019) and in RED-S research as it identifies the risk of poor bone health and declines in cardiovascular health. Both of these factors are recognized as symptoms on the RED-S spectrum and may be caused by a severe or chronic LEA state (American Academy of Family Physicians et al., 2019).

Athlete sleep behaviour questionnaire

The athlete sleep behaviour questionnaire (ASBQ) is a validated and reliable 18-item questionnaire to determine the sleep behaviour and habits of athletes (Driller et al., 2018). The ASBQ not only gives an overall assessment of sleep but allows for practitioners and researchers to gain insight into individuals' sleep behaviour. Participants rank sleep behaviours as 'never' 'rarely sometimes', or 'frequently' and 'always'. These responses are scored from 1-5. All scores are summed, giving a sleep behaviour score in which ≤36 represents good sleep behaviour (Driller et al., 2018). While ≥42 indicates poor sleep behaviour; participants with a score of ≥42 would have an average answer of 'frequently' and 'always' (Driller et al., 2018).

Profile of mood states

The short form of the POMS is an abbreviated yet validated 40-item survey based on the original 65-item POMS questionnaire (Grove & Prapavessis, 1992). For this study, depression and fatigue outcomes were the only information assessed. Previous research has consistently shown a high prevalence of depression, ED's and aspects of fatigue both physically and mentally in individuals presenting with RED-S because of being in an LEA state (Mountjoy et al., 2018). Questionnaires were scored from 0 "not at all" to 4 "extremely". The total score for depression and fatigue were calculated through the total scores of depression and fatigue specific questions as outlined by the POMS scoring.

Low energy availability female questionnaire

The low energy availability in the female questionnaire (LEAF-Q) is a validated 25-item questionnaire. The questionnaire focuses on the physiological symptoms of insufficient energy intake, injury frequency, gastrointestinal symptoms, and reproductive functions. The LEAF-Q questions were only answered by female participants and the answers were scored according to the LEAF-Q scoring key (Melin, 2013). Each question provided a score of points and was summed to provide an overall LEAF-Q score. From the original validation study, a LEAF-Q score of <8 is likely to be due to the presentation of less frequent LEA symptoms, deeming a low risk of an LEA state. Whereas a LEAF-Q score ≥8 was considered to be due to frequent presentations of LEA associated symptoms and as such these participants are then considered to be at a high risk of an LEA state (Melin et al., 2014). The LEAF-Q can be used effectively alongside other disordered eating screening tools when screening females for the risk of being in an LEA state (Melin et al., 2014)

Male low energy availability questionnaires

Due to the lack of male-specific LEA questionnaires such as the LEAF-Q, the male LEA scores were adapted from three validated questionnaires: gastrointestinal questions from the LEAF-Q, sexual desire inventory (SDI) and the androgen deficiency in aging males (ADAM). The questionnaire was only presented to male track athletes and was adjusted appropriately to encompass the age range of 16 - 35 and the range of athletic ability (e.g., local, national and international). The male questionnaire was scored according to the LEAF-Q gastrointestinal specific questions using the LEAF-Q scoring key (Melin, 2013). Sexual desire inventory questions were answered as 'yes', 'no' or 'maybe'. 'Yes', indicated a higher risk of low sexual desire than 'no' which shows a lower associated risk of an LEA state (Spector et al., 1996). Androgen deficiency in aging males was scored with answers of 'yes' given a numerical value of one and 'no' given a numerical score of zero (Morley et al., 2000). All surveys were used as specified by the initial survey validation studies (Melin et al., 2014; Morley et al., 2000; Spector et al., 1996). The scores of each section were added together in which the highest scores suggested a more frequent occurrence of symptoms (Melin et al., 2014; Morley et al., 2000; Spector et al., 1996). Due to the limited research of LEA in males and no currently available validated questionnaires to implement such as the LEAF-Q, this study assessed males' LEA scores by using the mean of the summed totals of each of the sections of the LEAF-Q score, SDI and ADAM. The mean of the total score for the male participants was determined. Male participants who scored below the mean showed less frequent LEA associated symptoms and therefore were not considered to be at risk of an LEA state. Those who scored greater than the mean reported more associated symptoms of LEA and therefore may be at a higher risk of an LEA state. Due to the social and workplace restrictions of the COVID-19 pandemic this study could not collect blood samples and physiological measures to validate the questionnaire, the results are considered as a risk of an LEA state and not a diagnosis.

Eating disorder examination

The EDE has been previously used to assess ED's among athlete populations (Sundgot-Borgen & Torstveit, 2004; Torstveit et al., 2008). The EDE has been referred to as an appropriate method in LEA research to assess the risk of ED's and DE, especially when combined with an interview (Gibbs et al., 2013; Melin et al., 2015; Mountjoy et al., 2018; Torstveit et al., 2019; Williams et al., 2017). The survey is scored and assessed in subscales which reflects the severity of aspects of the psychopathology of ED and DE including restraint, eating concern, shape concern, weight concern, global subscale score and global total score. Scoring is completed by the participant selecting an answer ("never" (1) to "always" (6)) which reflects their association to the content/question within the last three months. All scores of a specific category are added together and divided by the number of questions to give a subscale score. This is also completed for all questions to generate the global subscale score (Fairburn et al., 2014). A validity study of the EDE showed that a total subscale score ≥2.3 is an indication of DE behaviours (Mond et al., 2004).

Exercise dependence scale

The exercise dependence scale-21 (EDS-21) has been developed based on the criteria of substance dependence within the manual of mental disorders (Hausenblas & Downs, 2002a), and has been validated through various populations and studies (Hausenblas & Downs, 2002b). This is a 21-item questionnaire rated on a six-point scale from 'never' (1) to 'always' (6) in seven subscales (three questions comprise one subscale): tolerance, withdrawal, intention effect, lack of control, time, reduction in other activities, continuance, and the global score. This questionnaire then assesses the exercise dependence symptoms to differentiate whether participants are at risk of exercise dependence. It has been used in previous research which has looked at the relationship of RED-S in endurance cyclists (Torstveit et al., 2019), and the association with an LEA state (Kuikman et al., 2021). The scoring system indicates an individual is at risk of exercise dependence when they score > 15 on more than three subscales (Hausenblas & Downs, 2002b).

Statistical analysis

All statistical analyses were performed using IBM SPSS statistics version 27. Means and standard deviations (SD) were calculated for all groups. The data were checked for normality through a Levene's test, and non-normally distributed data were log-transformed. Male and female data were analyzed separately. Within each sex, the risk of LEA was determined. Differences in means for symptom presentation and risk factors between groups with and without risk of LEA were determined by one-way ANOVA. A value of $p<0.05$ was set to determine statistical significance. Where needed, log-transformed data were used within the one-way ANOVA and where there was insufficient data available, an independent t-test was used assuming unequal variance. The effect size was calculated through Cohen's *d* with medium (0.5) or large (0.8) effect sizes reported in the results.

3.3 Results

3.3.1 Participants

A total of 24 participants (female n = 14, male n = 10) who met the study inclusion criteria participated in the online survey. The characteristics of the participants are outlined in Table 2. Just under half (46%) of participants competed at more than one level of competition, with 38% competing locally, 83% competing nationally, 29% competing internationally and 17% at the elite age-group level.

Table 2: Descriptive characteristics, risk factors and symptoms associated with LEA of participants

	Male (n = 10)	*Female (n = 14)*
Age (years)	22 ± 6	22 ± 4
Ethnicity n, (%)		
New Zealand European	9 (90%)	13 (92.9%)
African	1 (10%)	0 (0%)
Māori	0 (0%)	1 (7.1%)
Competition level n, (%)		

Local/Community	1 (10%)		8 (57%)	
National	10 (100%)		10 (71%)	
International	2 (20%)		5 (35%)	
Elite Age Grouper	1 (10%)		3 (21%)	
	Not at risk of LEA	At risk of LEA	Not at risk of LEA	At risk of LEA
Risk assessment – LEA in males, LEAF-Q	5 (50%)	5 (50%)	6 (43%)	8 (57%)
Sleep score - ABSQ	37.4 ± 3.5$^{\lozenge}$	42.0 ± 6.6$^{\lozenge}$	37 ± 4.8***	42.8 ± 4.2***
Fatigue score - POMS	2.8 ± 1.9	2.4 ± 1.7	3.0 ± 1.9	3.8 ± 1.6
Depression score - POMS	2.0 ± 2.6	2.0 ± 2.4	0.8 ± 1.2***	5.9 ± 5.8***
'Eating disorder examination' categories				
Eating Restraint subscale	0.8 ± 0.9**	1.1 ± 1.5**	0.5 ± 0.4$^{**/\lozenge}$	2.4 ± 0.7$^{**/\lozenge}$
Eating concern subscale	0.0 ± 0.0$^{*/\lozenge}$	0.7 ± 1.2$^{*/\lozenge}$	0.2 ± 0.1$^{**/+}$	1.7 ± 0.6$^{**/+}$
Shape concern subscale	0.3 ± 0.2$^{\lozenge}$	1.7 ± 2.1$^{\lozenge}$	0.9 ± 0.5$^{\lozenge}$	2.9 ± 0.7$^{\lozenge}$
Weight concern subscale	0.5 ± 0.6$^{\lozenge}$	1.9 ± 2.2$^{\lozenge}$	0.5 ± 0.4***	2.1 ± 0.5***
Global EDE subscale	0.4 ± 0.2$^{\lozenge}$	1.4 ± 1.7$^{\lozenge}$	0.5 ± 0.3$^{**/***}$	2.3 ± 0.6$^{**/***}$
'Exercise dependence scale – 21' categories				
Exercise withdrawal effects	7.0 ± 4.2	7.0 ± 3.8	6.2 ± 2.6	6.8 ± 3.0
Continuance of exercise	8.0 ± 3.5$^{\lozenge}$	5.6 ± 1.5$^{\lozenge}$	5.3 ± 2.9	5.9 ± 3.0
Tolerance of exercise	11.0 ± 1.4$^{\lozenge/**}$	8.2 ± 3.4$^{\lozenge/**}$	7.2 ± 3.1^{+}	5.3 ± 2.1^{+}
Lack of control of exercise behaviours	9.0 ± 3.9^{+}	6.8 ± 2.9^{+}	5.5 ± 2.4	4.8 ± 2.5
Reduction in exercise activities	5.8 ± 1.5	6.2 ± 2.2	5.8 ± 2.6	5.9 ± 1.6
Time of exercise	9.8 ± 2.4	8.6 ± 3.6	9.3 ± 2.2^{+}	8.0 ± 2.3^{+}
Intention effects of exercise	5.2 ± 1.3$^{\lozenge}$	8.0 ± 4.0$^{\lozenge}$	6.2 ± 2.3^{+}	4.8 ± 1.8^{+}
Global EDS score	55.8 ± 15.6	50.4 ± 18.2	45.5 ± 15.6	41.3 ± 14.2

*Footnotes: *Independent t-test unequal variances assumed, ** unequal log-transformed data, ***Statistically significance at $p<0.05$*

+ Medium effect size, ◊ Large effect size

Abbreviations: LEA – Low energy availability, EDE – eating disorder examination, EDS – Exercise dependence scale

3.3.2 Low energy availability participant groups

Six female participants had a LEAF-Q score <8 and were considered not at risk of LEA, while eight female participants had a LEAF-Q score ≥8 and were deemed at risk of LEA. The mean score of the male LEA risk assessment questionnaire was 20 and used to determine whether a male participant was at risk of an LEA state or not. Five males had an LEA risk score <20 and were considered at low risk of LEA, while five males had an LEA risk score ≥20 and were considered to be at a high risk of LEA.

3.3.3 Association between the risk of low energy availability and frequency of illness, stress fracture and iron deficiency

The frequency of illness was grouped based on the number of times training was missed due to illness in the last 12 months. Two groups were identified and defined as ≥2 sessions missed due to illness (high illness) or <1 (low illness) trainings missed due to illness. Among females, the average LEAF-Q score was 10.86 (1.84) for the high illness (n = 7) and 7.71 (1.36) for the low illness group (n = 7), with no significant difference between the two groups (p = 0.2). Males' average LEA risk score was 22.1 (5.1) for the high illness group (n = 7) and 15.0 (7.9) for the low illness group (n = 3)), with no significant difference in LEA risk score between the two groups (p = 0.119). There were medium ($d = 0.7$) and large ($d = 1.2$) effect sizes for females and males, respectively. This suggests a trend that athletes who missed ≥2 trainings due to illness in the previous 12 months also present with a higher risk of LEA.

The frequency of stress fractures was grouped based on whether or not participants had experienced a stress fracture in their athletic careers. Among females, the average LEAF-Q score was 8.0 (2.1) for those who have had a stress fracture (n = 4) and 9.8 (1.5) for those who reported no previous stress fractures (n = 10), with no significant difference between the two groups (p = 0.5) and their risk of LEA. The average male LEA score was 18.7 (3.8) for those who had previously experienced a stress fracture (n = 3) and 20.6 (7.7) for those who had not experienced a stress fracture (n = 7), with no significant difference between males LEA risk and the frequency of stress fractures experienced in their athletic career (p = 0.7).

Iron deficiency

Participants were grouped depending on previous diagnoses of ID or IDA. Females' average LEAF-Q score was 8.4 (1.1) for those who had a previous ID/IDA diagnosis (*n* = 8), and 10.5 (2.4) for those females who had not (*n* = 6). No significant difference was found between females, suggesting no difference in LEA risk and diagnosis of ID (*p* = 0.4). Males' average LEA score was 22.5 (7.3) for those with a previous ID/IDA diagnosis (*n* = 4) and 18.3 (6.1) for males who did not, with no significant difference between male participant's LEA risk score and diagnosis of ID/IDA (*p* = 0.4). A medium effect size (*d = 0.6*) suggested that there was a trend where males with a higher LEA risk were also more likely to have been previously diagnosed with ID/IDA.

3.3.4 Sleep behaviour, fatigue, and depression score

One-way ANOVA suggested significant differences (*p* = 0.035) in sleep behaviour between females at risk and not at risk of LEA. Those who were at risk of LEA were more likely to have poorer sleep behaviour than those not at risk of LEA. Within male participants, a one-way ANOVA showed no significant difference between sleep scores (*p* = 0.208), however, a large negative effect size suggests a trend where males not at risk of LEA were likely to have better sleep practices/behaviours (*d = -0.87*). Fatigue scores showed no significant difference between the two female groups (*p* = 0.44) or the two male groups (*p* = 0.74) and LEA risk.

A Levene's test showed that female depression scores were not equally distributed, and data were log-transformed and used in a one-way ANOVA. Data showed a significant difference (*p* = 0.025) between depression scores in which females at risk of LEA had a higher depression score than females not at risk of LEA. A one-way ANOVA test for male participants showed no significant difference between depression scores between those not at risk of LEA and those at risk of LEA (*p* = 1.0).

3.3.5 Risk of low energy availability and eating disorder risk

A one-way ANOVA showed significant differences for females at risk of LEA in the EDE categories of weight concern (*p* = 0.04) and global EDE subscale (*p* = 0.049). However, there were no significant differences between female LEA risk groups and restraint from eating (*p* = 0.15,), eating concern (*p* = 0.39,), shape concern (*p* = 0.053). There was a large negative effect size for restraint and shape concern among females suggesting a trend that females not at risk of LEA were less likely to experience eating restraint (*d = -1.1*) or concern of their body shape (*d = -1.2*). Furthermore, a medium negative effect size of eating concern among females suggested a trend that females not at risk of LEA were less likely to be concerned over their eating behaviours compared to females at risk of LEA (*d = -0.71*).

There were no significant differences between male LEA risk groups and restraint from eating (*p* = 0.81), eating concern (*p* = 0.24), shape concern (*p* = 0.174), weight concern (*p* = 0.17), and global EDE subscale (*p* = 0.241). A large negative effect size for eating concern, body shape concern, weight concern and global subscale of EDE among males suggested a trend that males not at risk of LEA were less likely to have a higher concern of eating (*d = -0.863*), concern of body shape (*d = -0.945*), concern of weight (*d = -0.936*), and global EDE subscale scores (*d = -0.800*).

3.3.6 Risk of low energy availability and exercise dependence

One-way ANOVA suggested no significant difference between female LEA risk groups for withdrawal from exercise score *(p* = 0.71), continuance (*p* = 0.74) or tolerance (*p* = 0.195,).

Furthermore, a medium effect size was observed among females' tolerance, suggesting a trend that females not at risk of LEA are more likely to have a higher tolerance to exercise *(d = 0.741*) when compared to females at risk of LEA. There was no significant differences between female LEA risk groups for lack of control (*p* = 0.5), reduction in activities (*p* = 0.97), time (*p* = 0.29), intention effects (*p* = 0.22), and global EDS subscale score (*p* = 0.6). In addition, there was a positive medium effect size for time and intention effects of exercise among females suggesting a trend that females not at risk of LEA are more likely to spend more time exercising (*d = 0.6*), have a higher tolerance to exercise (*d = 0.74)* and intention to exercise (*d = 0.71*) than females at risk of LEA.

Among male LEA risk groups one-way ANOVA showed no significant differences between withdrawal from exercise score (*p* = 1.0), continuance (*p* = 0.2) or tolerance (*p* = 0.1). There was a large positive effect size for continuance and tolerance among males, suggesting a trend for males not at risk of LEA being more likely to have a higher continuance of exercise training (*d = 0.882*) and tolerance *(d = 1.049*) when compared to males at risk of LEA. There was no significant difference between LEA risk groups for lack of control (*p* = 0.3), reduction in activities (*p* = 0.74), time (*p* = 0. 55), intention effects (*p* = 0.18) and global EDS subscale score (*p* = 0.63). There was a positive medium effect size and negative large effect size among males for lack of control and intention effects of exercise respectively. This suggests a trend for males not at risk of LEA being more likely to have a lack of control over exercise behaviours and habits (*d = 0.646*) and are less likely to have higher intention to exercise than males at risk of LEA (*d = -0.94*).

3.4 Discussion

To our knowledge, this is the first study to examine LEA risk amongst both male and female track specialist athletes. Our data suggests that among our study population, 57% of female and 50% of male track athletes could be at risk of LEA, with symptoms that may affect their health, wellbeing, and performance. This aligns with research that looked specifically at 13 elite female sprinters' prevalence of LEA associated symptoms pre and post a 5-month training block. Of the 13 sprinters, seven (54%) displayed at least one primary and one secondary indicator associated with an LEA state (Sygo et al., 2018). The results in this current study were similar, with 8 (57%) females returning a LEAF-Q score ≥8 suggesting that they may be at risk of being in an LEA state. While both studies had small sample sizes, the high prevalence of LEA risk within both sexes warrants further investigation to identify the physiological implications of LEA in this athletic population. This pilot study also highlighted several key factors among female and male athletes, in relation to their physical attributes and eating behaviours associated with LEA risk. Female participants in this study at risk of LEA were more concerned about their weight and presented with a higher EDE global score in comparison to females, not at risk of LEA.

In comparison to females, there is currently limited research evidence in males of LEA risk or associated risk factors. Research has addressed the physiological implications of severe LEA in males over 3-5 days (Ishibashi et al., 2020; Koehler et al., 2016). A small number of reviews provide additional insight on potential risk factors of LEA, and the long-term impact of LEA on male athletes (Areta et al., 2020a; Burke et al., 2018; Elliott-Sale et al., 2018). Within this current study, five (50%) of the male athletes presented with a substantial number of symptoms associated with LEA. These symptoms included a higher frequency of illness, ID/IDA, negative sleeping behaviours, concerns over body weight, body shape and overall EDE assessment. Male athletic populations deemed vulnerable to an LEA state include cyclists, combat sports, jockeys, rowers, and endurance runners (Burke et al., 2018). These males are considered at risk of LEA due to drastic changes in body mass to meet competition or race requirements. In addition, the failure to meet high energy demands through nutritional intake is associated with LEA in male athletes, due to the demands of training and events (Burke et al., 2018). Therefore, our findings highlight, that male athletes competing in sprinting may also be at risk of an LEA state due to risk factors such as intentionally or unintentionally under fuelling themselves in order to influence performance outcomes or bodyweight changes. Hence, it would not be unexpected that this population might present with LEA symptoms as observed in our female participants.

Investigations into LEA associated symptoms such as frequency of illness showed no significant difference in male or female participants based on their risk of LEA. However, large and medium effect sizes were observed in male and female athletes, respectively. This suggests a trend of a high incidence of illness being associated with a higher risk of being in an LEA state in both male and female sprint special athletes. The results accept the hypothesis that sprint specialist athletes at risk of LEA will have a higher incidence of illness. Our results align with a study in elite female and male athletes prior to the 2016 Olympics in which a state of LEA was identified as a risk factor for illness (Drew et al., 2017). It also showed that females were more likely to have a greater risk of illness in comparison to male athletes. However, findings derived from cross-sectional studies lack the ability to draw casual links between LEA and illness (Areta et al., 2020a; Walsh, 2019). In relation to athletes' increased risk of illness due to LEA, consideration should be given to the amount of psychological stress (e.g., performance, race anxiety, family pressure, emotional stress), travel, poor sleep, presence of pre-existing illness symptoms and risk of ID/IDA that likely contribute to the risk of illness within athletes. Therefore, it should be considered what role those within an athlete's support environment can do to reduce the risk of illness. Within the world of athletics and sprinting, coaches, health professionals and family members may need to consider illness or ID/IDA symptoms such as showing signs of earlier fatigue, lethargy, dizziness/light-headedness, irritability and more frequent illness episodes as early presentations of an LEA state.

Assessment of ID/IDA showed no significant difference between LEA risk groups in this study. There was a trend though for females and males at risk of an LEA state to have previously been diagnosed with ID/IDA. Iron deficiency is noted as a common diagnosis in female athletes, with some researchers suggesting that it may exacerbate the negative health outcomes associated with an LEA state (e.g. further reducing the metabolic state associated with energy status, reproductive function and bone health) (Petkus et al., 2017). Our findings reflect that of a larger study assessing health and performance factors in 1000 female athletes in an LEA state. The research indicated that participants at risk of LEA were 1.6 times more likely to report a history of a hematological issue (e.g., ID/IDA diagnosis) (Ackerman et al., 2019). Risk factors of a negative iron balance include reducing or restricting the overall intake of food groups (especially iron-rich foods) and high iron demand through exercise. The consequences of a negative iron balance can result in an ID/IDA diagnosis within a state of LEA (Petkus et al., 2017). Negative health implications from low iron status with or without anemia decreases the body's metabolic efficiency (e.g., exercise tolerance and reduced aerobic capacity), increased illness susceptibility and can reduce cognitive function and mood (Beard, 2001; DellaValle & Haas, 2011). Therefore, ID/IDA diagnosis may be a resulting factor from an LEA state in sprinters, therefore, it is important that practitioners are mindful of screening athletes for ID. It is especially important that coaches are aware of at-risk populations such as females and potential risk factors associated with LEA, ID/IDA diagnosis such as mood, illness and performance declines.

This study's investigation of sleep behaviours found that females at risk of LEA had significantly poorer sleep behaviours. A large positive trend among male athletes suggested those at risk of LEA were more likely to experience poorer sleep behaviours. These results support our hypothesis that athletes at risk of LEA will have a higher sleep score, indicative of poor sleep. Our results align with previous research showing that LEA influences the quality of an individual's sleep. Research found that of 81 Olympic athletes (26 males and 55 females) 73% of athletes had compromised sleep behaviours (Drew et al., 2017), of which 53% of female athletes were at risk of LEA. Poor sleep within athletic populations is not an uncommon finding. Factors that affect athletes' sleep are late training/competition times, poor sleep hygiene (e.g., caffeine and alcohol consumption, training, and sleep schedule, napping and travel), training load, injury, travel or environment (Drew et al., 2017; Pitchford et al., 2017). In addition, research has also suggested a probable link between sleep, injury, and illness, thus reinforcing the negative outcomes of poor sleep in an athletic cohort (Drew et al., 2017; Fullagar et al., 2015). Total sleep time reduction negatively impacts mood, cognition, injury, illness, and performance (Fullagar et al., 2015; Mountjoy et al., 2018). The understanding of how poor sleep affects performance outcomes, and the health of athletes is important for the development and performance of sprinting focused athletes. Therefore, clubs and support staff like coaches, need to understand multiple associated behaviours effecting sleep within the context of LEA. The understanding of support staff is important to help guide sprinting athletes to reduce possible risk of LEA, to gain the benefits of improved sleep behaviours, which will benefit training adaptions and increase overall performance. There is a need to focus on aiding sleep hygiene and positive sleep behaviours amongst athletes. This is because it may prevent the exacerbation of negative health outcomes associated with an LEA state (e.g., mood, fatigue, concentration, reaction time). This current research aligns with many reviews on LEA/RED-S that future research needs to clarify the impact of sleep and LEA on athletes' health, wellbeing, and performance. An area where more research is needed is the understanding of the link between reports of reduced sleeping behaviours and higher amounts of depression and stress measured in comparison to those not at risk of LEA (Drew et al., 2017).

Depression scores in this study were significantly different in female athletes at risk of LEA than those not at risk of LEA, showing higher depression scores. This supports our hypothesis that athletes at risk of LEA will have a higher risk of depressive tendencies. However, similar findings were not noted in the male cohort. The psychological impact of LEA is bidirectional with one of the adverse outcomes being declines in mood and an increase in irritation (Mountjoy et al., 2018). Results from our female cohort, therefore, align with previous cross-sectional research demonstrating that female athletes at risk of LEA are 1.6 and 2.3 times more likely to experience irritability and depression respectively (Ackerman et al., 2019). Increases in depression have been seen as a likely outcome of an LEA state because it affects the mental and psychological wellbeing of an athlete. However, the psychological factors that contribute to an LEA state need to be considered in research and in practice. Psychological risk factors can be the aetiology of ED/DE and EXD because of the pressures over body shape, weight and expectations of performance (Heather et al., 2021; Wasserfurth et al., 2020). Overall, this shows that more research is needed to understand both the psychological influence of an LEA state and how psychological behaviour can lead to a state of LEA. The identification of poor mood states and LEA in this study, especially in females, shows that clubs, support staff and athletes themselves should look at being able to identify changes in general well-being or mood.

The restraint in eating behaviours or concern over body shape was not significantly different between female LEA risk groups. This study did show that restraint in eating and concern over their body shape had a large effect size for females at risk of LEA. The result was similar for males suggesting that those at risk of LEA were more likely to be concerned over their eating, body shape and weight in comparison to males not at risk of LEA. Males at risk of LEA were also more likely to have a higher global EDE score compared to males not at risk of LEA. Energy intake is a critical component within the dynamics of energy availability. The common aetiology of LEA for both male and female athletes stems from negative eating behaviours such as ED/DE where restriction of energy intake, with aims to manipulate their weight or influence body image. However, the causal factors of LEA are considered multifactorial and can present with or without DE (Mountjoy et al., 2018; Nattiv et al., 2007; Williams et al., 2017). Research does highlight that the risk of LEA appears to be increased in males and females that present with DE or ED (Williams et al., 2017). Disordered eating and ED stem from perceived pressures to attain a certain athletic, feminine, or masculine body image (Heather et al., 2021; Wasserfurth et al., 2020).

These perceptions can be accentuated by social media, coaches, peers and elite athlete role models (Heather et al., 2021; Wasserfurth et al., 2020). Alternatively, DE can be due to the consistent pursuit of a body composition perceived to produce better performances or to fit weight class sports categories (Areta et al., 2020a; Mountjoy et al., 2018; Wasserfurth et al., 2020). The female cohort in this study at risk of LEA also demonstrated a high risk of ED, with a mean global EDE score of 2.3 ± 0.6 which in previous research is shown to indicate ED pathology (Müller et al., 2015a). Our results also highlighted those females at risk of LEA appeared to be concerned about their body weight and body shape and were more likely to present with restrictive eating behaviours. Our research also suggested a trend for males at risk of LEA having a higher risk of ED/DE. The male cohort appeared to be concerned about their shape and weight, and therefore these psychological factors may influence their food intake. In agreement with our findings, research in sprinting and middle-distance runners has suggested that athletes may be conflicted between their body weight/shape and the physical needs for sports performance and improvements (Sundgot-Borgen & Torstveit, 2010). This previous research has suggested that ED appeared more frequently in sprinting and middle-distance runners who perceived that their sport had a key emphasis on body size or shape, power to weight ratios and weight categories compared to non-athletic controls (Burke et al., 2018; Sundgot-Borgen & Torstveit, 2010). In recent research in New Zealand elite female athletes, 54% believed that they needed to uphold the stereotypical perception and expectation of a feminine appearance due to pressures from social media, themselves, the general public and other media (Heather et al., 2021). Of the study cohort, 73% believed that participation in elite sport required a specific physical appearance of looking healthy, fit and strong (Heather et al., 2021). However, athletes also struggled with the feeling they had to look pretty and feminine alongside their required physical appearance (Heather et al., 2021). Moreover, 15% of these elite athletes had reported engaging in disordered eating behaviours to try and achieve an 'ideal' body shape (Heather et al., 2021). It was also reported that 22 participants were told by coaches to lose weight for performance-related reasons, impacting the participants' mood, feelings of unhappiness with their body, and being upset, angry and/or un-motived (Heather et al., 2021). To date, the majority of ED and DE research has focused on female athletes due to the belief that they were more susceptible to these behaviours when compared to males (Wasserfurth et al., 2020). Our results align with this and previous research suggesting that DE/ED behaviours may predispose female athletes to a state of LEA. Therefore DE/ED behaviours should be a factor that is considered in female athlete health and wellbeing screening. Research in ED/DE is continuously developing within male athlete populations. Our results align with previous reviews, suggesting that male athletes are at risk of ED/DE if they feel pressure to attain a specific athletic body image (Wasserfurth et al., 2020). Therefore, the awareness of this perceived physical appearance pressure may also be considered for male athletes during health and wellbeing screens.

An unhealthy relationship in regard to body images such as shape and weight can influence individuals to have compulsive or dependent tenancies towards exercise (Bratland-Sanda et al., 2019; Dittmer et al., 2018). Exercise dependence or compulsive exercise is a contributing risk factor of LEA. This study showed no significant differences in the components of exercise dependence when compared to the risk of LEA, however, some trends were observed. The investigation in female athletes found trends that those who were not at risk of LEA appeared to have greater intention to obtain a desired effect from exercise, spend more time on exercise-related activities and had a higher tolerance towards exercise. Our results do not align with research focused on female exercise dependence. Previously, research on females and exercise dependence has been paired with conditions of ED's rather than LEA (Bratland-Sanda et al., 2011). The research compared longstanding ED patients with non-clinical controls, finding those female ED patients scored significantly higher in all exercise dependent areas (e.g., withdrawal, continuance, lack of control) except tolerance (Bratland-Sanda et al., 2011). For female sprinters at risk of LEA, it may mean that there less tolerance in being able to perform high training volumes required for sprinting. It could also be that those at risk of LEA consider their amount or behaviours of exercise to be normal.

When comparing male athletes in this study no significant difference was noticed between those at risk and those not at risk of LEA. Males at risk of LEA scored lower on continuance, tolerance and lack of control. This trend suggested that males at risk of LEA are less likely to continue exercise due to the lack of tolerance to maintain a large amount of exercise output and lack of control over the amount of exercise.

However, our research also showed trends in which males at risk of LEA were more likely to seek intentional effects from exercise. Overall, our findings are different compared to other research which saw male endurance athletes presenting with higher total exercise dependence scores, specifically significantly higher category scores (e.g., withdrawal, lack of control, intention) apart from continuance (Torstveit et al., 2019). This could mean that males at risk of LEA competing in sprinting may subsequently have less energy to continue the high volumes of training required in comparison to those not at risk of an LEA state. The findings in our study suggest a trend that males at risk of LEA have a higher intention of effects towards exercise. This means that despite a low continuance for male sprinters at risk of LEA, they had significant intentions to try and complete the full session and volumes of training. The results of the EDE suggest that intentions to complete larger amounts of training could be driven by physical attributes such as body image or power to weight ratios. This is because research shows that exercise dependence and ED/DE behaviours are associated (Torstveit et al., 2019). This would mean that males at risk of LEA are concerned over their body shape and weight which contributes to them wanting to gain intentional effects from exercise possibly leading to detrimental effects such as LEA.

Exercise compulsiveness suggests that an individual's need to exercise is similar to that of addictive behaviour (Bratland-Sanda et al., 2019; Dittmer et al., 2018). Individuals that present with exercise dependence are likely to present with behaviours that manifest as the inability to reduce exercise load until physical or physiological consequences occur (Torstveit et al., 2019). There were differences in which athletes in our study at risk of LEA reported trends that they had lower tolerance to exercise. This possibly highlights the differences in how athletes in high-intensity sports are not able to tolerate consistent long-term exercise loads like endurance athletes. This means that an LEA state could have diminishing effects on their abilities and exercise performance (Hausenblas & Downs, 2002a). These findings could suggest that screening for exercise dependence tendencies and risk of LEA may vary between high-intensity sports athletes and endurance athletes. Therefore, more research in larger population groups of New Zealand sprinters is needed to assess and understand possible trends of exercise dependence within a high-intensity sports group (Torstveit et al., 2019).

To conclude, this research supports justification for more LEA/RED-S research in athletes involved in short duration, high-intensity events. Key findings include that 50% of males and 57% of female participants were identified to be at risk of LEA. The key negative health outcomes noted for females at risk of LEA were decreased sleep behaviours and quality, risk of depression, a concern of weight in relation to eating and as well a greater risk of ED based on their global EDE score. Our study showed that there were large trends that suggested males at risk of LEA were more likely to have negative health outcomes such as poorer sleep behaviours, concern over their eating behaviour, body shape and weight as well suggesting more risk of overall EDE assessment. This research can be used to inform health practitioners and coaches on physiological and psychological risk factors for sprint focused athletes. These are important risk factors of LEA that should be considered when screening athletes' health, performance and wellbeing. This study provides pilot data and results on which to base future research within this cohort of athletes to better understand the physiological and psychological impacts of an LEA state, as well as the prevalence of LEA risk in male and female track athletes in New Zealand. These findings support the proposition that further research in sprint athletes with low exercise volume should also be considered when investigating an LEA state and presentation of RED-S symptoms.

Chapter 4: Research conclusions

4.0 Conclusion

It is important to understand that the risk of a low energy availability (LEA) state is not limited to endurance or female athletes. The current study has demonstrated that both male and female athletes competing in high-intensity sports (e.g., sprinting), at an amateur-elite level are at risk of being in an LEA state. This is reflective of previous research that has also demonstrated the prevalence of risk of LEA in elite female sprinters (Sygo et al., 2018). Both this study and research in elite sprinters have shown that more than 50% of female sprinters show symptoms associated with an LEA state, a result of high LEAF-Q scores and high eating disorder (ED) risk. This research has shown that high-intensity sports athletes are also at risk of psychological risk factors associated with LEA such as disordered eating/eating disorders (DE)/ED. The behaviours of these athletes are possibly driven by a drive for thinness, pressures from oneself, and perceived pressures from coaches, peers, family, sporting culture and social media that they must look a certain way to perform well (Heather et al., 2021; Sundgot-Borgen & Torstveit, 2010). Research has shown that elite athletes are more at risk of ED/DE than non-athletes (Sundgot-Borgen & Torstveit, 2010). Trends over the last decade have shown that ED/DE are increasing across both sexes with male athletes more at risk than non-athletic females (Torstveit et al., 2008). For sprinters, this increasing level of ED/DE among athletic populations can also be due to feeling that their body's adaptions from their training (e.g. high load and strength work to increases in muscle mass) do not fit the normative athletic figure stereotypes set by society (especially females) (Sundgot-Borgen & Torstveit, 2010). Furthermore, the growing changes in athletic and performance clothing may add to the stress of body image for athletes (Heather et al., 2021). The pressure of maintaining sponsorships among athletes may also reduce the level of choice they have over their performance/training clothing.

Other risk factors of ED/DE in athletes may be driven by performance outcomes. Research has shown that the risk of LEA can also occur due to the high levels of energy expenditure through exercise (EEE) and attempting to achieve perceived optimal power to weight ratios for performance (e.g., running and cycling) causing individuals to undertake disordered eating behaviours (Burke et al., 2018; Melin et al., 2019; Torstveit et al., 2019). These behaviours include intentionally restricting food or displaying exercise dependent behaviours. Failure to meet EEE through energy intake (EI) has been shown to reduce the energy available for healthy physiological functioning (Loucks et al., 2011). The potential outcomes of an LEA state in sprinters could include negative consequences such as the increased risk of injury, iron deficiency/iron deficiency anaemia (ID/IDA), illness, poorer sleep behaviours , reduced mood and reduced muscle adaption to high-intensity training. The negative physiological consequences due to LEA highlight that future research in sprinting populations needs to quantify the risk of LEA further. In addition, research should aim to understand the causes that lead to LEA, such as DE/ED in sprinters. This could help provide education that could be beneficial for athletes to mitigate the risk of LEA and negative health and performance effects. Important areas for athletes to understand is how to reduce the risk of LEA and this may include understanding their energy requirements, nutrition strategies on how to fuel, body adaptions to exercise, sport-specific performance outcomes and identification of early physiological changes/symptoms associated with LEA. Support should not only be directed to athletes but also to individuals who have a role within the athlete's journey. Athletic clubs can also facilitate this support between coaches, researchers, and health workers to improve the performance, health, and well-being outcomes for athletes.

Thinking of outcomes for athletes, more needs to be done to quantify the physiological outcomes. This study was unable to investigate biomarkers such as resting metabolic rate (RMR), lean body mass (LBM), EEE, EI, cognition and muscle strength and endurance as outlined by ethics due to the COVID-19 pandemic and restrictions on social gatherings, data collection and workplace access. Biomarkers associated with LEA including markers from blood collection (e.g., leptin, oestrogen, testosterone, IGF-1, GH, iron) and bone mineral density is needed in research to assess physiological outcomes of an LEA state. Despite these markers not being measured, this research was still able to identify risk factors associated with being in a state of LEA like exercise dependence and negative eating behaviours. This study also outlined the potential prevalence of LEA within the sprinting populations through the use of

LEAF-Q and three validated questionnaires around sexual desire, androgen levels and gastrointestinal function for males. This study was unable to collect EEE and EI data because of a lack of compliance, likely due to stress associated with the COVID-19 pandemic. However, the importance of these measures is to help researchers quantify estimated EA levels in athletes. Data of EEE and EI along with survey responses from the LEAF-Q or a similar questionnaire in males could be used to determine the severity of an LEA state in these athletes. Energy intake and EEE however are still subject to errors through self-reporting and more needs to be done in the evolution of data collection for EEE and EI that reduces the error that may allow future testing within a field environment.

Previous research has identified that sporting culture contributes to the attitudes of individuals within sport (Burke et al., 2018; Torstveit et al., 2019). This study did not investigate whether this was an influencing factor for sprinting athletes. Understanding the attitudes within the sprinting culture would give more insight into influences that contribute to the findings of this study in regard to exercise dependence and eating behaviours.

In conclusion, these findings show that sprinting populations are at risk of an LEA state. This may be due to risk factors associated with the aetiology of LEA, such as DE/ED behaviours due to psychological influences from body image, society's heterosexual normativity of body shape, pressures of being an athlete (e.g., body shape, sportswear), and the pressures of performance outcomes. Furthermore, an athlete can face psychological pressures from coaches, peers, family members and social media which may exaggerate LEA outcomes (Heather et al., 2021). The results from this study would suggest that sprinters at risk of LEA will experience several negative outcomes including poor mood, sleep behaviours, increased risk of eating disorders, increased risk of illness and ID/IDA. This suggests that more research in sprinting populations is needed as they are at risk of LEA risk factors and negative health and sports performance outcomes.

4.1 Strengths and limitations

This study provides valuable insight into the risk of LEA in male and female sprinting populations in New Zealand. For this study to identify a statistical significance in some of the measured variables a sample size of 36 (18 male and 18 female) participants was needed. Unfortunately, this number of participants was unable to be reached during the time period of the 2019/20 and 2020/21 track athletic season. Though the number of 24 (10 male and 14 female) participants was larger than that of previous research which investigated 13 elite female sprinters (Sygo et al., 2018), it still shows that further investigation is needed within sprinting populations.

The limitations of this study are the inability to quantify physiological markers associated with LEA such as lean body mass and resting metabolic rate, muscle strength and endurance, cognition, EEE and EI. The inability to record these physiological markers were due to COVID-19 restrictions imposing lockdowns and the inability to physically collect data from participants. The study was able to connect with participants in an online manner in which participants completed an online questionnaire comprised of validated questionnaires. Participants were able to complete the online survey in their own time and from an environment where they would feel comfortable. A strength of our study was that the inclusion of validated questionnaires focused on risk factors and symptoms associated with LEA. This included questionnaires on sleep behaviour (Driller et al., 2018), eating disorder examination (EDE) (Fairburn et al., 2014; Mond et al., 2004), exercise dependence (Hausenblas & Downs, 2002a), mood (Grove & Prapavessis, 1992) and general well-being (American Academy of Family Physicians et al., 2019). Furthermore, a strength of this was that the risk assessment of LEA in female participants was able to be quantified by the LEAF-Q as shown in previously validated studies (Melin et al., 2014). In comparison to males, a weakness in this study is the limitation that there is no male equivalent of the LEAF-Q. However, the use of three validated questionnaires to create a male risk assessment of LEA also added as a strength to this study. This is because there is not the same abundance of research in male athletes and LEA risk assessment when compared to females. Therefore, the inclusion of male athletes is a strength because it contributes to the growing body of research in understanding the male risk of an LEA and associated risk factors.

This study has also added to the growing research of the prevalence of LEA in athletes outside of endurance-based sports such as cycling, triathlon, and long-distance running. Furthermore, as there is one study that has specifically looked at LEA prevalence in elite female sprinters (Sygo et al., 2018), A strength of our study is that it identified the prevalence of LEA within amateur-elite level athletes. This is important because more research is needed to understand the risk of LEA and associated risk factors in high-intensity sports. Therefore, this research can also provide insight into associated risk factors of LEA that are impacting athletes from a younger age or competition level. Future research should also aim to identify and quantify LEA physiological markers in sprinting populations.

4.2 Future recommendations

To date, only one study has looked at the prevalence of LEA in elite female sprinters in pre-season training. The study was able to also measure biological markers associated with LEA such as amenorrhea, bone mineral density, low FSH and LH, RMR and LEAF-Q. This study aimed to identify the prevalence of LEA in male and female amateur-elite athletes during the athletic season. Future recommendations for research include the use of biological markers and risk factors associated with an LEA state throughout different training cycles (e.g., off-season, pre-season, event-season). This would be important because it would be able to identify when sprinting athletes are most at risk of an LEA state. This would help direct support from the likes of coaches, health professionals and family members to support the athletes in reducing the risk of LEA before there are negative physiological consequences. To build the understanding of LEA in high-intensity-sport athletic males, and male athletes in general, future research should aim to create and validate a male equivalent of the LEAF-Q to establish male LEA risk. Regarding population groups, future research should aim to include a larger cohort from New Zealand or specific country sprinting populations (male and female). Future cohorts would also need to reflect the country's ethnic groups (e.g., NZ European, Māori, Asian, Pacific peoples). The importance of more research that focuses on the associated risk factors causing LEA would be helpful to direct education requirements. This would be valuable information for coaches, sports clubs, health professionals, family members and the athletes themselves. Research should be able to increase the knowledge of those supporting athletes to help influence sporting culture and athletes' attitudes towards behaviours that are detrimental to their overall health, well-being and performance. Concerning the measurement of EA, there should a focus on minimising errors of under or over-reporting of self-reporting food diaries and energy expenditure data. The ability to collect comprehensive data would add value to research. Furthermore, allowing an athlete to report from their own environment (e.g., home and training) may give insight into environmental pressures through analysis of LEA associated risk factors. The inclusiveness of the risk factors associated with causing LEA in research can help guide specific knowledge deficits such as food preparation or adequate nutrition requirements for sport (e.g., nutrients, total energy).

Overall, these future recommendations would help give a greater understanding of sprinting populations' risk of LEA throughout their full training calendar. It would help give insight into more male-associated risk factors and physiological outcomes of LEA. Furthermore, it could be a key to understanding the association of risk factors of LEA in sprinting populations where stereotypical behaviours such as exercise dependence are not as rife, however, unsafe nutritional practices (e.g., ED/DE) may be causing lower amounts of energy available for healthy physiological function.

References

Ackerman, K. E., Holtzman, B., Cooper, K. M., Flynn, E. F., Parziale, A. L., Bruinvels, G., . . . Popp, K. L. (2019). Low energy availability surrogates correlate with health and performance consequences of Relative Energy Deficiency in Sport [Article]. *British Journal of Sports Medicine*, *53*(10), 628-633. https://doi.org/10.1136/bjsports-2017-098958

American Academy of Family Physicians, American Academy of Pediatrics, American College of Sports Medicine, & American Medical Society for Sports Medicine. (2019). *PPE: Preparticipation Physical Evaluation* (Vol. 5th edition) [Book]. American Academy of Pediatrics. http://ezproxy.massey.ac.nz/login?url=https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,cookie,url,uid&db=nlebk&AN=2117009&site=eds-live&scope=site&authtype=sso&custid=s3027306

Areta, J. L., Burke Lm Fau - Camera, D. M., Camera Dm Fau - West, D. W. D., West Dw Fau - Crawshay, S., Crawshay S Fau - Moore, D. R., Moore Dr Fau - Stellingwerff, T., . . . Coffey, V. G. (2014). Reduced resting skeletal muscle protein synthesis is rescued by resistance exercise and protein ingestion following short-term energy deficit. (1522-1555 (Electronic)).

Areta, J. L., Taylor, H. L., & Koehler, K. (2020a). Low energy availability: history, definition and evidence of its endocrine, metabolic and physiological effects in prospective studies in females and males [Review Paper]. *European Journal of Applied Physiology*, 1. https://doi.org/10.1007/s00421-020-04516-0

Beard, J. L. (2001). Iron biology in immune function, muscle metabolism and neuronal functioning. *The Journal of nutrition*, *131*(2S-2), 568S-579S. https://doi.org/10.1093/jn/131.2.568S

Beitins, I. Z., Mc arthur, J. W., Turnbull, B. A., Skrinar, G. S., & Bullen, B. A. (1991). Exercise induces two types of human luteal dysfunction: Confirmation by urinary free progesterone [Article]. *Journal of Clinical Endocrinology and Metabolism*, *72*(6), 1350-1358. https://doi.org/10.1210/jcem-72-6-1350

Bomba, M., Corbetta, F., Bonini, L., Gambera, A., Tremolizzo, L., Neri, F., & Nacinovich, R. (2014). Psychopathological traits of adolescents with functional hypothalamic amenorrhea: a comparison with anorexia nervosa [Original Paper]. *Eating and Weight Disorders - Studies on Anorexia, Bulimia and Obesity: Official Journal of the Italian Society for the Study of Eating Disorders (SISDCA)*, *19*(1), 41. https://doi.org/10.1007/s40519-013-0056-5

Bomba, M., Gambera, A., Bonini, L., Peroni, M., Neri, F., Scagliola, P., & Nacinovich, R. (2007). Endocrine profiles and neuropsychologic correlates of functional hypothalamic amenorrhea in adolescents [Article]. *Fertility and Sterility*, *87*(4), 876-885. https://doi.org/10.1016/j.fertnstert.2006.09.011

Bratland-Sanda, S., Mathisen, T. F., Sundgot-Borgen, J., & Rosenvinge, J. H. (2019). Defining compulsive exercise in eating disorders: Acknowledging the exercise paradox and exercise obsessions. *Journal of Eating Disorders*, *7*. https://doi.org/10.1186/s40337-019-0238-2

Bratland-Sanda, S., Rã, A., Hoffart, A., Sundgot-Borgen, J., Martinsen, E. W., & Rosenvinge, J. H. (2011). Exercise dependence score in patients with longstanding eating disorders and controls: The importance of affect regulation and physical activity intensity [Article]. *European Eating Disorders Review*, *19*(3), 249-255. https://doi.org/10.1002/erv.971

Bronson, F. H. (1985). Mammalian reproduction: An ecological perspective [Review]. *Biology of Reproduction*, *32*(1), 1-26. https://doi.org/10.1095/biolreprod32.1.1

Brugh, D. D., Williford, J. H., Chibucos, T. R., & Shewokis, P. A. (2001). The frequency of eating disorder tendencies among male high school wrestlers, non wrestler athletes, and nonathletes. *Journal of the American Dietetic Association*, *101*(9). https://doi.org/10.1016/S00028223(01)80294-7

Bullen, B. A., Skrinar, G. S., Beitins, I. Z., von Mering, G., Turnbull, B. A., & McArthur, J. W. (1985). Induction of Menstrual Disorders by Strenuous Exercise in Untrained Women. *New England Journal of Medicine*, *312*(21), 1349-1353. https://doi.org/10.1056/nejm198505233122103

Burke, L. M., Close, G. L., Lundy, B., Mooses, M., Morton, J. P., & Tenforde, A. S. (2018). Relative Energy Deficiency in Sport in Male Athletes: A Commentary on Its Presentation Among Selected Groups of Male Athletes. *International Journal of Sport Nutrition & Exercise Metabolism*, *28*(4), 364-374. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=131027217&site=eds-live&scope=site

Burrows, T. L. H., Y. Y.;
Rollo,M. E.;
Collins, C. E.;. (2019). Validity of Dietary Assessment Methods When Compare to the Method of Doubly Labeled Water: A Systematic Review in Adults. *Frontiers in Endocrinology*. https://doi.org/https://doi.org/10.3389/fendo.2019.00850

Civil, R., Lamb, A., Loosmore, D., Ross, L., Livingstone, K., Strachan, F., . . . Witard, O. C. (2019). Assessment of Dietary Intake, Energy Status, and Factors Associated With RED-S in Vocational Female Ballet Students. *Frontiers in nutrition*, *5*, 136. https://doi.org/10.3389/fnut.2018.00136

Condo, D., Lohman, R., Carr, A., & Kelly, M. (2019). Nutritional intake, sports nutrition knowledge and energy availability in female Australian rules football players. *Nutrients*, *11*(5). https://doi.org/https://doi.org/10.3390/nu11050971

Cook, B. J., & Hausenblas, H. A. (2008). The role of exercise dependence for the relationship between exercise behavior and eating pathology: Mediator or moderator? *Journal of Health Psychology*, *13*(4), 495-502. https://doi.org/10.1177/1359105308088520

Cook, B. J., Wonderlich, S. A., Mitchell, J. E., Thompson, R. O. N., Sherman, R., & McCallum, K. (2016). Exercise in Eating Disorders Treatment: Systematic Review and Proposal of Guidelines. *Medicine & Science in Sports & Exercise*, *48*(7), 1408-1414. http://ezproxy.massey.ac.nz/login?url=https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,cookie,url,uid&db=s3h&AN=116222510&site=eds-live&scope=site&authtype=sso&custid=s3027306

De Souza, M. J., Hontscharuk, R., Olmsted, M., Kerr, G., & Williams, N. I. (2007). Drive for thinness score is a proxy indicator of energy deficiency in exercising women [Article]. *Appetite*, *48*(3), 359-367. https://doi.org/10.1016/j.appet.2006.10.009

De Souza, M. J., Koltun, K. J., Strock, N. C. A., & Williams, N. I. (2019). Rethinking the concept of an energy availability threshold and its role in the Female Athlete Triad [Review Article]. *Current Opinion in Physiology*, *10*, 35-42. https://doi.org/10.1016/j.cophys.2019.04.001

De Souza, M. J., Koltun, K. J., & Williams, N. I. (2019a). The Role of Energy Availability in Reproductive Function in the Female Athlete Triad and Extension of its Effects to Men: An Initial Working Model of a Similar Syndrome in Male Athletes. *Sports medicine (Auckland, N.Z.)*, *49*(Suppl 2), 125-137. https://doi.org/10.1007/s40279-019-01217-3

De Souza, M. J., Koltun, K. J., & Williams, N. I. (2019b). What is the evidence for a Triad-like syndrome in exercising men? [Review Article]. *Current Opinion in Physiology*, *10*, 27-34. https://doi.org/10.1016/j.cophys.2019.04.002

De Souza, M. J., Lee, D. K., Scheid, J. L., West, S. L., VanHeest, J. L., & Williams, N. I. (2007). Severity of energy-related menstrual disturbances increases in proportion to indices of energy conservation in exercising women [Article]. *Fertility and Sterility*, *88*(4), 971-975. https://doi.org/10.1016/j.fertnstert.2006.11.171

De Souza, M. J., & Williams, N. I. (2004). Physiological aspects and clinical sequelae of energy deficiency and hypoestrogenism in exercising women. In (Vol. 10, pp. 433-448).

DellaValle, D. M., & Haas, J. D. (2011). Impact of iron depletion without anemia on performance in trained endurance athletes at the beginning of a training season: A study of female collegiate rowers [Article]. *International Journal of Sport Nutrition and Exercise Metabolism*, *21*(6), 501-506. https://doi.org/10.1123/ijsnem.21.6.501

Dipla, K., Kraemer, R. R., Constantini, N. W., & Hackney, A. C. (2020). Relative energy deficiency in sports (RED-S): elucidation of endocrine changes affecting the health of males and females. *Hormones (Athens, Greece)*. https://doi.org/10.1007/s42000-020-00214-w

Dittmer, N., Jacobi, C., & Voderholzer, U. (2018). Compulsive exercise in eating disorders: proposal for a definition and a clinical assessment [article]. *Journal of Eating Disorders*, *6*(1), 1-9.

https://doi.org/10.1186/s40337-018-0219-x
Dolan, E., McGoldrick, A., Davenport, C., Kelleher, G., Byrne, B., Tormey, W., . . . Warrington, G. D. (2012). An altered hormonal profile and elevated rate of bone loss are associated with low bone mass in professional horse-racing jockeys. *Journal of Bone and Mineral Metabolism*, *30*(5), 534-542. https://doi.org/10.1007/s00774-012-0354-4
Douka, A., Skordilis, E., Koutsouki, D., Theodorakis, Y.,. (2008). Prevalence of eating disorders among elite female athletes in aquatic sports. *Inquiries in Sport & Physical Education*, *6*, 87–96.
Drew, M., Vlahovich, N., Hughes, D., Appaneal, R., Burke, L. M., Lundy, B., . . . West, N. P. (2018). Prevalence of illness, poor mental health and sleep quality and low energy availability prior to the 2016 summer Olympic games [Article]. *British Journal of Sports Medicine*, *52*(1), 47-53. https://doi.org/10.1136/bjsports-2017-098208
Drew, M. K., Vlahovich, N., Hughes, D., Appaneal, R., Peterson, K., Burke, L., . . . West, N. (2017). A multifactorial evaluation of illness risk factors in athletes preparing for the Summer Olympic Games [Article]. *Journal of Science and Medicine in Sport*, *20*(8), 745-750. https://doi.org/10.1016/j.jsams.2017.02.010
Driller, M. W., Mah, C. D., & Halson, S. L. (2018). Development of the athlete sleep behavior questionnaire: A tool for identifying maladaptive sleep practices in elite athletes [Article]. *Sleep Science*, *11*(1), 37-44. https://doi.org/10.5935/1984-0063.20180009
Elliott-Sale, K. J., Tenforde, A. S., Parziale, A. L., Holtzman, B., & Ackerman, K. E. (2018). Endocrine Effects of Relative Energy Deficiency in Sport. *International Journal of Sport Nutrition & Exercise Metabolism*, *28*(4), 335-349. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=131027213&site=eds-live&scope=site
Fagerberg, P. (2018). Negative Consequences of Low Energy Availability in Natural Male Bodybuilding: A Review. *International Journal of Sport Nutrition & Exercise Metabolism*, *28*(4), 385-402. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=131027205&site=eds-live&scope=site
Fahrenholtz, I. L., Sjödin, A., Benardot, D., Tornberg, Å. B., Skouby, S., Faber, J., . . . Melin, A. K. (2018). Within-day energy deficiency and reproductive function in female endurance athletes. *Scandinavian Journal of Medicine & Science in Sports*, *28*(3), 1139-1146. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=128209830&site=eds-live&scope=site
Fairburn, C., Cooper, Z., & O'Connor, M. (2014). Eating Disorder Examination. In (17 ed.).
Ferrand, C., Magnan, C., Rouveix, M., Filaire, E. (2007). Disordered eating, perfectionism and body-esteem of elite synchronized swimmers. *European Journal of Sport Science*, *7*(4), 223-230. https://doi.org/10.1080/17461390701722168
Fullagar, H. H. K., Skorski, S., Duffield, R., Hammes, D., Coutts, A. J., & Meyer, T. (2015). Sleep and athletic performance: The effects of sleep loss on exercise performance, and physiological and cognitive responses to exercise. *Sports Medicine*, *45*(2), 161-186. https://doi.org/10.1007/s40279-014-0260-0
Gibbs, J. C., Williams, N. I., & De Souza, M. J. (2013). Prevalence of Individual and Combined Components of the Female Athlete Triad. *Medicine & Science in Sports & Exercise*, *45*(5), 985-996. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=87106179&site=eds-live&scope=site
Gibbs, J. C., Williams, N. I., Scheid, J. L., Toombs, R. J., & De Souza, M. J. (2011). The Association of a High Drive for Thinness With Energy Deficiency and Severe Menstrual Disturbances: Confirmation in a Large Population of Exercising Women. *International Journal of Sport Nutrition & Exercise Metabolism*, *21*(4), 280-290. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=64745377&site=eds-live&scope=site
Gomez-Merino, D., Chennaoui, M., Drogou, C., Bonneau, D., & Guezennec, C. Y. (2002). Decrease in serum leptin after prolonged physical activity in men. *Medicine & Science in Sports & Exercise*, *34*(10), 1594-1599.

http://ezproxy.massey.ac.nz/login?url=https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,cookie,url,uid&db=edsovi&AN=edsovi.00005768.200210000.00010&site=eds-live&scope=site&authtype=sso&custid=s3027306

Goodwin, Y., Monyeki, M. A., Boit, M. K., De Ridder, J. H., Toriola, A. L., Mwangi, F. M., & Wachira, J. L. (2014). Association between energy availability and menstrual function in elite Kenyan runners. *African Journal for Physical, Health Education, Recreation & Dance*, *20*(2.1), 291-307. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=102958264&site=eds-live&scope=site

Grandner, M. A. (2017). Sleep, Health, and Society. *Sleep Medicine Clinics*, *12*(1), 1-22. https://doi.org/https://doi.org/10.1016/j.jsmc.2016.10.012

Grove, J. R., & Prapavessis, H. (1992). Preliminary evidence for the reliability and validity of an abbreviated Profile of Mood States. *International journal of Sport Psychology*, *23*(2), 93-109.

Hackney, A. C., & Hackney, Z. C. (2005). The exercise-hypogonadal male condition and endurance exercise training. (0972-947X (Print)).

Hackney, A. C., & Lane, A. R. (2018). Low testosterone in male endurance-trained distance runners: impact of years in training [Letter]. *Hormones: International Journal of Endocrinology and Metabolism*, *17*(1), 137. https://doi.org/10.1007/s42000-018-0010-z

Hackney, A. C., Lane, A. R., Register-Mihalik, J., & O'Leary, C. B. (2017). Endurance Exercise Training and Male Sexual Libido. *Medicine & Science in Sports & Exercise*, *49*(7), 1383-1388. https://doi.org/10.1249/MSS.0000000000001235

Hausenblas, H. A., & Downs, D. S. (2002a). Exercise Dependence Scale-21 Manual In.

Hausenblas, H. A., & Downs, D. S. (2002b). How much is too much? The development and validation of the Exercise Dependence Scale. *Psychology & Health*, *17*(4), 387–404. https://doi.org/10.1080/0887044022000004894

Heaney, S., O'Connor, H., Geraldine, N., & Gifford, J. (2008). Towards an Understanding of the Barriers to Good Nutrition for Elite Athletes. *International Journal of Sports Science & Coaching*, *3*(3), 391-401. http://ezproxy.massey.ac.nz/login?url=https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,cookie,url,uid&db=s3h&AN=34992233&site=eds-live&scope=site&authtype=sso&custid=s3027306

Heather, A. K., Thorpe, H., Ogilvie, M., Sims, S. T., Beable, S., Milsom, S., . . . Hamilton, B. (2021). Biological and Socio-Cultural Factors Have the Potential to Influence the Health and Performance of Elite Female Athletes: A Cross Sectional Survey of 219 Elite Female Athletes in Aotearoa New Zealand [Original Research]. *Frontiers in Sports and Active Living*, *3*(27). https://doi.org/10.3389/fspor.2021.601420

Heikkilä, M., Valve, R., Lehtovirta, M., & Fogelholm, M. (2018). Nutrition Knowledge Among Young Finnish Endurance Athletes and Their Coaches. *International Journal of Sport Nutrition & Exercise Metabolism*, *28*(5), 522–527.

Heikura, I. A., Uusitalo, A. L. T., Stellingwerff, T., Bergland, D., Mero, A. A., & Burke, L. M. (2018). Low Energy Availability Is Difficult to Assess but Outcomes Have Large Impact on Bone Injury Rates in Elite Distance Athletes. *International Journal of Sport Nutrition & Exercise Metabolism*, *28*(4), 403-411. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=131027207&site=eds-live&scope=site

Holtzman, B., Tenforde, A. S., Parziale, A. L., & Ackerman, K. E. (2019). Characterization of Risk Quantification Differences Using Female Athlete Triad Cumulative Risk Assessment and Relative Energy Deficiency in Sport Clinical Assessment Tool. *International Journal of Sport Nutrition & Exercise Metabolism*, *29*(6), 569-575. https://doi.org/10.1123/ijsnem.2019-0002

Howe, S. M., Hand, T. M., Larson-Meyer, D. E., Austin, K. J., Alexander, B. M., & Manore, M. M. (2016). No Effect of Exercise Intensity on Appetite in Highly-Trained Endurance Women. . *Nutrients* *8*(4). https://doi.org/doi: 10.3390/nu8040223

Ikedo, A., Ishibashi, A., Matsumiya, S., Kaizaki, A., Ebi, K., & Fujita, S. (2016). Comparison of site-specific bone mineral densities between endurance runners and sprinters in adolescent women. *Nutrients*, *8*(12). https://doi.org/ doi:10.3390/nu8120781

Ishibashi, A., Kojima, C., Tanabe, Y., Iwayama, K., Hiroyama, T., Tsuji, T., . . . Takahashi, H. (2020). Effect of low energy availability during three consecutive days of endurance training on iron metabolism in male long distance runners [article]. *Physiological Reports*, *8*(12). https://doi.org/10.14814/phy2.14494

Koehler, K., Hoerner, N. R., Gibbs, J. C., Zinner, C., Braun, H., De Souza, M. J., & Schaenzer, W. (2016). Low energy availability in exercising men is associated with reduced leptin and insulin but not with changes in other metabolic hormones. *Journal of Sports Sciences*, *34*(20), 1921-1929. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=118238182&site=eds-live&scope=site

Kojima, C., Ishibashi, A. Y. A., Tanabe, Y., Iwayama, K., Kamei, A., Takahashi, H., & Goto, K. (2020). Muscle Glycogen Content during Endurance Training under Low Energy Availability. *Medicine & Science in Sports & Exercise*, *52*(1), 187-195. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=140335514&site=eds-live&scope=site

Kuikman, M. A., Mountjoy, M., & Burr, J. F. (2021). Examining the Relationship between Exercise Dependence, Disordered Eating, and Low Energy Availability. *Nutrients*, *13*(8). https://doi.org/10.3390/nu13082601

Lane, A. R., Hackney, A. C., Smith-Ryan, A., Kucera, K., Registar-Mihalik, J., & Ondrak, K. (2019). Prevalence of low energy availability in competitively trained male endurance athletes [Article]. *Medicina (Lithuania)*, *55*(10). https://doi.org/10.3390/medicina55100665

Larson-Meyer, D. E., Palm, S., Bansal, A., Austin, K. J., Hart, A. M., & Alexander, B. M. (2012). Influence of running and walking on hormonal regulators of appetite in women. *Journal of obesity*. https://doi.org/https://doi.org/10.1155/2012/730409

Lichtenstein, M. B., Andries, A., Hansen, S., Frystyk, J., & Stoving, R. K. (2015). Exercise addiction in men is associated with lower fat-adjusted leptin levels [Article]. *Clinical Journal of Sport Medicine*, *25*(2), 138-143. https://doi.org/10.1097/JSM.0000000000000110

Lieberman, J. L., MJ, D. E. S., Wagstaff, D. A., & Williams, N. I. (2018). Menstrual Disruption with Exercise Is Not Linked to an Energy Availability Threshold. *Medicine & Science in Sports & Exercise*, *50*(1530-0315 (Electronic)), 551 - 561.

Logue, D., Madigan, S., Delahunt, E., Heinen, M., Mc Donnell, S.-J., & Corish, C. (2018). Low Energy Availability in Athletes: A Review of Prevalence, Dietary Patterns, Physiological Health, and Sports Performance. *Sports Medicine*, *48*(1), 73-96. https://doi.org/10.1007/s40279-017-0790-3

Logue, D. M., Madigan, S. M., Melin, A., Delahunt, E., Heinen, M., Donnell, S.-J. M., & Corish, C. A. (2020). Low Energy Availability in Athletes 2020: An Updated Narrative Review of Prevalence, Risk, Within-Day Energy Balance, Knowledge, and Impact on Sports Performance. *Nutrients*, *12*(3), 835. https://doi.org/10.3390/nu12030835

Loucks, A., Kiens, B., & Wright, H. (2011). Energy availability in athletes. *Journal of Sports Sciences*, *29*, S7-S15. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=69537746&site=eds-live&scope=site

Loucks, A. B. (2004). Energy balance and body composition in sports and exercise. *Journal of Sports Sciences*, *22*(1), 1-14. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=11715044&site=eds-live&scope=site&authtype=sso&custid=s3027306

Loucks, A. B. (2007). Low Energy Availability in the Marathon and Other Endurance Sports [Original Paper]. *Sports Medicine*, *37*(4-5), 348. https://doi.org/10.2165/00007256-200737040-00019

Loucks, A. B. (2020). Exercise Training in the Normal Female: Effects of Low Energy Availability on Reproductive Function. In A. C. Hackney & N. W. Constantini (Eds.), *Endocrinology of Physical Activity and Sport* (pp. 171-191). Springer International Publishing. https://doi.org/10.1007/978-3-030-33376-8_11

Loucks, A. B., & Callister, R. (1993). Induction and prevention of low-T3 syndrome in exercising women. *American Journal of Physiology: Regulatory, Integrative & Comparative Physiology*, *33*(5), R924. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=edb&AN=96971000&site=eds-live&scope=site

Loucks, A. B., & Heath, E. M. (1994a). Induction of low-T3 syndrome in exercising women occurs at a threshold of energy availability. *American Journal of Physiology: Regulatory, Integrative & Comparative Physiology*, *35*(3), R817. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=edb&AN=97886123&site=eds-live&scope=site

Loucks, A. B., Heath, E. M., Law, T., Verdun, M., & Watts, J. R. (1994b). Dietary restriction reduces luteinizing hormone (LH) pulse frequency during waking hours and increases LH pulse amplitude during sleep in young menstruating women [Article]. *Journal of Clinical Endocrinology and Metabolism*, *78*(4), 910-915. https://doi.org/10.1210/jcem.78.4.8157720

Loucks, A. B., Laughlin, G. A., Mortola, J. F., Girton, L., Nelson, J. C., & Yen, S. S. C. (1992). Hypothalamic-pituitary-thyroidal function in eumenorrheic and amenorrheic athletes [Article]. *Journal of Clinical Endocrinology and Metabolism*, *75*(2), 514-518. https://doi.org/10.1210/jcem.75.2.1639953

Loucks, A. B., Stachenfeld, N. S., & DiPietro, L. (2006). The female athlete triad: do female athletes need to take special care to avoid low energy availability? *Medicine & Science in Sports & Exercise*, *38*(10), 1694-1700. https://doi.org/10.1249/01.mss.0000239397.01203.83

Loucks, A. B., & Thuma, J. R. (2003). Luteinizing Hormone Pulsatility Is Disrupted at a Threshold of Energy Availability in Regularly Menstruating Women. *The Journal of Clinical Endocrinology & Metabolism*, *88*(1), 297-311. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=edsovi&AN=edsovi.00004678.200301000.00052&site=eds-live&scope=site&authtype=sso&custid=s3027306

Loucks, A. B., & Verdun, M. (1998). Slow restoration of LH pulsatility by refeeding in energetically disrupted women [Article]. *American Journal of Physiology - Regulatory Integrative and Comparative Physiology*, *275*(4 44-4), R1218-R1226. https://doi.org/10.1152/ajpregu.1998.275.4.r1218

Marcus, M. D., Loucks, T. L., & Berga, S. L. (2001). Psychological correlates of functional hypothalamic amenorrhea [Article]. *Fertility and Sterility*, *76*(2), 310-316. https://doi.org/10.1016/S0015-0282(01)01921-5

Mathisen, T. F., Heia, J., Raustøl, M., Sandeggen, M., Fjellestad, I., & Sundgot-Borgen, J. (2020). Physical health and symptoms of relative energy deficiency in female fitness athletes. *Scandinavian Journal of Medicine & Science in Sports*, *30*(1), 135-147. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=140158125&site=eds-live&scope=site

McCarthy, S. F., Islam, H., & Hazell, T. J. (2020). The emerging role of lactate as a mediator of exercise-induced appetite suppression. *American Journal of Physiology. Endocrinology and metabolism*, *319*(4), E814–E819. https://doi.org/https://doi.org/10.1152/ajpendo.00256.2020

Melin, A. (2013). The LEAF-Q Scoring key. http://www.diva-portal.org/smash/get/diva2:1303041/FULLTEXT03.pdf

Melin, A., Tornberg, A. B., Skouby, S., Faber, J., Ritz, C., Sjödin, A., & Sundgot-Borgen, J. (2014). The LEAF questionnaire: a screening tool for the identification of female athletes at risk for the female athlete triad. *British Journal of Sports Medicine*, *48*(7), 540-545. https://doi.org/10.1136/bjsports-2013-093240

Melin, A., Tornberg, Å. B., Skouby, S., Møller, S. S., Sundgot-Borgen, J., Faber, J., . . . Sjödin, A. (2015). Energy availability and the female athlete triad in elite endurance athletes. *Scandinavian Journal of Medicine & Science in Sports*, *25*(5), 610-622. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=109462573&site=eds-live&scope=site

Melin, A. K., Heikura, I. A., Tenforde, A., & Mountjoy, M. (2019). Energy Availability in Athletics: Health, Performance, and Physique. *International Journal of Sport Nutrition & Exercise Metabolism*, *29*(2), 152-164. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db

=s3h&AN=135936371&site=eds-live&scope=site
Mond, J. M., Hay, P. J., Rodgers, B., Owen, C., & Beumont, P. J. V. (2004). Validity of the Eating Disorder Examination Questionnaire (EDE-Q) in screening for eating disorders in community samples. *Behaviour Research and Therapy*, *42*(5), 551–567. https://doi.org/doi:10.1016/S0005-7967(03)00161-X
Morley, J. E., Charlton, E., Patrick, P., Kaiser, F. E., Cadeau, P., McCready, D., & Perry, H. M. (2000). Validation of a screening questionnaire for androgen deficiency in aging males [Article]. *Metabolism*, *49*(9), 1239-1242. https://doi.org/10.1053/meta.2000.8625
Mountjoy, M., Sundgot-Borgen, J., Burke, L., Ackerman, K. E., Blauwet, C., Constantini, N., . . . Budgett, R. (2018). International Olympic Committee (IOC) Consensus Statement on Relative Energy Deficiency in Sport (RED-S): 2018 Update. *International Journal of Sport Nutrition & Exercise Metabolism*, *28*(4), 316-331. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=131027214&site=eds-live&scope=site
Mountjoy, M., Sundgot-Borgen, J., Burke, L., Carter, S., Constantini, N., Lebrun, C., . . . Ljungqvist, A. (2014). The IOC consensus statement: beyond the Female Athlete Triad—Relative Energy Deficiency in Sport (RED-S). *British Journal of Sports Medicine*, *48*(7), 491-497. https://doi.org/10.1136/bjsports-2014-093502
Müller, A., Loeber, S., Söchtig, J., Te Wildt, B., & De Zwaan, M. (2015a). Risk for exercise dependence, eating disorder pathology, alcohol use disorder and addictive behaviors among clients of fitness centers. *JOURNAL OF BEHAVIORAL ADDICTIONS*, *4*(4), 273-280. https://doi.org/10.1556/2006.4.2015.044
Murphy, C., & Koehler, K. (2020). Caloric restriction induces anabolic resistance to resistance exercise [Original Paper]. *European Journal of Applied Physiology*, *120*(5), 1155. https://doi.org/10.1007/s00421-020-04354-0
Nattiv, A., Loucks, A. B., Manore, M. M., Sanborn, C. F., Sundgot-Borgen, J., & Warren, M. P. (2007). American College of Sports Medicine position stand. The female athlete triad. *Medicine and science in sports and exercise*, *39*(10), 1867-1882. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=cmedm&AN=17909417&site=eds-live&scope=site
Nikolaidis, P. T., & Knechtle, B. (2020). Validity of Recreational Marathon Runners' Self-Reported Anthropometric Data. *Perceptual & Motor Skills*, *127*(6), 1068–1078.
Olds, T., Norton, K., Craig, N., Olive, S., & Lowe, E. (1995). The limits of the possible: models of power supply and demand in cycling. *Australian Journal of Science and Medicine in Sport*, *27*(2), 29-33.
Papageorgiou, M., Dolan, E., Elliott-Sale, K. J., & Sale, C. (2018). Reduced energy availability: implications for bone health in physically active populations. *European Journal of Nutrition*, *57*(3), 847-859. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=128598008&site=eds-live&scope=site
Papageorgiou, M., Elliott-Sale, K. J., Parsons, A., Tang, J. C. Y., Greeves, J. P., Fraser, W. D., & Sale, C. (2017). Effects of reduced energy availability on bone metabolism in women and men [Article]. *Bone*, *105*, 191-199. https://doi.org/10.1016/j.bone.2017.08.019
Petkus, D. L., Murray-Kolb, L. E., & De Souza, M. J. (2017). The Unexplored Crossroads of the Female Athlete Triad and Iron Deficiency: A Narrative Review [Review Paper]. *Sports Medicine*, *47*(9), 1721. https://doi.org/10.1007/s40279-017-0706-2
Pitchford, N. W., Robertson, S. J., Sargent, C., Cordy, J., Bishop, D. J., & Bartlett, J. D. (2017). Sleep Quality but Not Quantity Altered With a Change in Training Environment in Elite Australian Rules Football Players. *International Journal of Sports Physiology & Performance*, *12*(1), 75-80. http://ezproxy.massey.ac.nz/login?url=https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,cookie,url,uid&db=edb&AN=121191353&site=eds-live&scope=site&authtype=sso&custid=s3027306
Redman, L. M., Heilbronn, L. K., Martin, C. K., de Jonge, L., Williamson, D. A., Delany, J. P., & Ravussin, E. (2009). Metabolic and Behavioral Compensations in Response to Caloric

Restriction: Implications for the Maintenance of Weight Loss [Article]. *PLoS ONE*, *4*(2), 1-9. https://doi.org/10.1371/journal.pone.0004377

Reed, J. L., Bowell, J. L., Hill, B. R., Williams, B. A., De Souza, M. J., & Williams, N. I. (2011). Exercising women with menstrual disturbances consume low energy dense foods and beverages. *Applied Physiology, Nutrition & Metabolism*, *36*(3), 382–394.

Reed, J. L., De Souza, M. J., Kindler, J. M., & Williams, N. I. (2014). Nutritional practices associated with low energy availability in Division I female soccer players. *Journal of Sports Sciences*, *32*(16), 1499-1509. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=97440804&site=eds-live&scope=site

Robertson, S., & Mountjoy, M. (2018). A Review of Prevention, Diagnosis, and Treatment of Relative Energy Deficiency in Sport in Artistic (Synchronized) Swimming. *International Journal of Sport Nutrition & Exercise Metabolism*, *28*(4), 375-384. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=131027209&site=eds-live&scope=site

Rouveix, M., Bouget, M., Pannafieux, C., Champely, S., & Filaire, E. (2007). Eating attitudes body esteem, perfectionism and anxiety of judo athletes and nonathletes. *International Journal of Sports Medicine*, *28*(4), 340–345. https://doi.org/10.1055/s2006-924334

Seijo, M., Minckas, N., Cormick, G., Comande, D., Ciapponi, A., & Belizan, J. M. (2018). Comparison of self-reported and directly measured weight and height among women of reproductive age: a systematic review and meta-analysis. *Acta Obstetricia et Gynecologica Scandinavica*, *97*(4), 429–439. https://doi.org/https://doi.org/10.1111/aogs.13326

Spector, I. P., Carey, M. P., & Steinberg, L. (1996). Sexual Desire Inventory [PsycTESTSRecord]. *Journal of Sex & Marital Therapy*, *22*(3), 175-190. https://doi.org/10.1037/t59616-000

Sundgot-Borgen, J., & Torstveit, M. K. (2004). Prevalence of Eating Disorders in Elite Athletes Is Higher Than in the General Population [Article]. *Clinical Journal of Sport Medicine*, *14*(1), 25-32. https://doi.org/10.1097/00042752-200401000-00005

Sundgot-Borgen, J., & Torstveit, M. K. (2010). Aspects of disordered eating continuum in elite high-intensity sports. *Scandinavian Journal of Medicine & Science in Sports*, *20*, 112-121. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=53474880&site=eds-live&scope=site

Sygo, J., Coates, A. M., Sesbreno, E., Mountjoy, M. L., & Burr, J. F. (2018). Prevalence of Indicators of Low Energy Availability in Elite Female Sprinters. *International Journal of Sport Nutrition & Exercise Metabolism*, *28*(5), 490-496. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=132020482&site=eds-live&scope=site

Tenforde, A., Barrack, M., Nattiv, A., & Fredericson, M. (2016). Parallels with the Female Athlete Triad in Male Athletes. *Sports Medicine*, *46*(2), 171-182. https://doi.org/10.1007/s40279-015-0411-y

Tornberg, Ä. B., Melin, A., Manderson Koivula, F., Johansson, A., Skouby, S., Faber, J., & SjÖDin, A. (2017). Reduced Neuromuscular Performance in Amenorrheic Elite Endurance Athletes. *Medicine & Science in Sports & Exercise*, *49*(12), 2478-2485. http://ezproxy.massey.ac.nz/login?url=https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,cookie,url,uid&db=s3h&AN=126249194&site=eds-live&scope=site&authtype=sso&custid=s3027306

Torstveit, M. K., Fahrenholtz, I. L., Stenqvist, T. B., Lichtenstein, M. B., & Melin, A. K. (2019). Exercise dependence, eating disorder symptoms and biomarkers of Relative Energy Deficiency in Sports (RED-S) among male endurance athletes [Article]. *BMJ Open Sport and Exercise Medicine*, *5*(1). https://doi.org/10.1136/bmjsem-2018-000439

Torstveit, M. K., Rosenvinge, J. H., & Sundgot-Borgen, J. (2008). Prevalence of eating disorders and the predictive power of risk models in female elite athletes: a controlled study. *Scandinavian Journal of Medicine & Science in Sports*, *18*(1), 108-118. http://ezproxy.massey.ac.nz/login?url=https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,cookie,url,uid&db=s3h&AN=29984936&site=eds-live&scope=site&authtype=sso&custid=s3027306

Tritos, N. A., & Klibanski, A. (2016). Effects of Growth Hormone on Bone. *Prog Mol Biol Transl Sci*, *138*, 193-211. https://doi.org/10.1016/bs.pmbts.2015.10.008

Viner, R. T., Harris, M., Berning, J. R., & Meyer, N. L. (2015). Energy Availability and Dietary Patterns of Adult Male and Female Competitive Cyclists With Lower Than Expected Bone Mineral Density. *International Journal of Sport Nutrition & Exercise Metabolism*, *25*(6), 594-602. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=112931121&site=eds-live&scope=site

Vinther, A., Kanstrup, I. L., Christiansen, E., Alkjaer, T., Larsson, B., , Magnusson, S. P., & Aagaard, P. (2006). Exercise-induced rib stress fractures: Potential risk factors related to thoracic muscle co-contraction and movement pattern. *Scandinavian Journal of Medicine & Science in Sports*, *16*(3), 188–196. https://doi.org/doi:10.1111/j.1600-0838.2005.00473.x

Vinther, A., Kanstrup, I. L., Christiansen, E., Ekdahl, C., & Aagaard, P. (2008). Testosterone and BMD in elite male lightweight rowers. *International Journal of Sports Medicine*, *29*(10), 803–807. https://doi.org/10.1055/s-2008-1038430

Wade, G. N., & Jones, J. E. (2004). Neuroendocrinology of nutritional infertility [Review]. *American Journal of Physiology - Regulatory Integrative and Comparative Physiology*, *287*(6 56-6), R1277-R1296. https://doi.org/10.1152/ajpregu.00475.2004

Walsh, N. P. (2018). Recommendations to maintain immune health in athletes. *European Journal of Sport Science*, *18*(6), 820-831. http://ezproxy.massey.ac.nz/login?url=https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,cookie,url,uid&db=s3h&AN=147237327&site=eds-live&scope=site&authtype=sso&custid=s3027306

Walsh, N. P. (2019). Nutrition and Athlete Immune Health: New Perspectives on an Old Paradigm [Review Paper]. *Sports Medicine*, *49*(Suppl 2), 153. https://doi.org/10.1007/s40279-019-01160-3

Warden, S. J., Edwards, W. B., & Willy, R. W. (2021). Preventing Bone Stress Injuries in Runners with Optimal Workload. *Current Osteoporosis Reports*, *19*(3), 298–307. https://doi.org/https://doi.org/10.1007/s11914-021-00666-y

Wasserfurth, P., Palmowski, J., Hahn, A., & Krüger, K. (2020). Reasons for and Consequences of Low Energy Availability in Female and Male Athletes: Social Environment, Adaptations, and Prevention [Review Paper]. *Sports Medicine - Open*, *6*(1). https://doi.org/10.1186/s40798-020-00275-6

Williams, N. I., Leidy, H. J., Hill, B. R., Lieberman, J. L., Legro, R. S., & De Souza, M. J. (2015). Magnitude of daily energy deficit predicts frequency but not severity of menstrual disturbances associated with exercise and caloric restriction. *Amrican Journal of Physiology-Endocrinology and Metabolism*, *308*(1522-1555 (Electronic)).

Williams, N. I., Statuta, S. M., & Austin, A. (2017). Female Athlete Triad: Future Directions for Energy Availability and Eating Disorder Research and Practice. *Clinics in Sports Medicine*, *36*(4), 671-686. http://ezproxy.massey.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=125021816&site=eds-live&scope=site

Appendices

Appendix A: Information sheet

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

An assessment on the prevalence of symptoms of low energy availability and Relative Energy Deficiency in Sport (RED-S) in New Zealand track athletes

Information Sheet

Researchers Introduction

We would like to invite you to participate in this study investigating low energy availability and Relative Energy Deficiency in Sport syndrome in track athletes. The purpose of this study is to investigate the prevalence, risk factors and consequences to performance specific to males and females competing in track running events. This study is being conducted by a group of researchers at Massey University, Auckland, New Zealand.

Please read the Information Sheet carefully before deciding whether or not to participate.
The details of the lead researcher for this study are:

Dr Claire Badenhorst
Lecturer
School of Sport, Exercise and Nutrition
College of Health
Massey University
Email: C.Badenhorst@massey.ac.nz
Phone: (09) 414 0800 ext 43410

Project Description and invitation

Energy availability is the difference between the energy we get from food and the energy we expend during exercise. This remaining energy is utilised by the body to maintain normal physiological functioning. Low energy availability can result in a number of negative health consequences including declines in bone health, increased injury risk, poor reaction times and declines in muscle strength. While behaviours and risk factors associated with low energy availability have been investigated in endurance and team sport settings, the implications of RED-S in track specialists is currently unknown. Therefore, the aim of the study is to investigate prevalence, risk factors and performance outcomes in male and female track running athletes in New Zealand.

Participant Identification and Recruitment

Who are we looking for?

We are looking for male and female athletes that meet the following inclusion criteria: -
Aged 16 – 35 years of age
- Have competed in a 100m, 200m, 400m, 800m, 1500m, 3000m, 5000m, steeple chase and short and long hurdles track events
- Currently competing and have competed for a minimum one season within New Zealand - Competed from 2019 onwards
- Athletes that are injured are invited to complete all sections of the data collection that will not aggravate their current injury
- Professional and non-professional athletes
- Willing and able to provide 7 days of training data (including HR monitors)
- Be proficient in English

Project procedures

What is going to happen?

If you decide to take part in this study after you have read and had time to consider the information contained in this information sheet, you will be asked to complete a short screening questionnaire to ensure that you meet the study criteria. If you meet the inclusion criteria you will be invited to take part in the study. If you are willing to participate, you will be invited to complete the following:

1) Series of online questionnaires: these questionnaires will cover symptoms associated with RED-S, sleep, injury, health and mental well-being
2) Body composition analysis: first through Bioimpedance Analysis scales (BIA) and secondly through sum of skinfolds according to ISAK criteria. These will be completed in a private room for all participants
3) Resting metabolic rate at Massey University Sport and Exercise Lab, Albany
4) Reaction time and neuro-cognitive functioning via Stroop test at Massey University Sport and Exercise Lab, Albany
5) Knee muscle maximal strength and knee muscle endurance at Massey University Sport and Exercise Lab. Albany

The survey will be completed in private at a time that suits the participant

The measurements conducted at the Massey University Sport and Exercise Lab will be collected between 7-10 am. The total length of time required for this session is around 90 minutes.

Data Management

The data will be used only for the purposes of this project and no individual will be identified. Only the investigators and administrators of the study will have access to personal information and this will be kept secure and strictly confidential. Participants will be identified only by a study identification number. Results of this project may be published or presented at conferences or seminars and no individual will be able to be identified.

At the end of this study the list of participants and their study identification number will be disposed of. Any raw data on which the results of the project depend will be retained in secure storage for 5 years, after which it will be destroyed.

A summary of the project findings will be available to all study participants. All participants will be sent this information via email or a personal letter.

Participants Rights:

You are under no obligation to accept this invitation. Should you choose to participate, you have the right to:

- Decline to answer any particular question
- Withdraw from the study at any time, even after signing a consent form (if you choose to withdraw you cannot withdraw your data from the analysis after the data collection has been completed)
- Ask any questions about the study at any time during participation
- Provide information on the understanding that your name will not be used unless you give permission to the researcher
- Be given access to a summary of the project findings when it is concluded

What are the benefits and risks of taking part in this study?

There will be no cost to you for any of the procedures or assessments taken as part of this study. The principle benefit of taking part in this study is that you will contribute to a novel area of research and assist us in increasing our understanding of factors that influence REDS among track athletes in New Zealand

There are no personal risks to your health as a result of completing this research.

Project Contacts:

If you have any questions regarding this study, please do not hesitate to contact either of the following people for assistance:

Principal Researcher:
Dr Claire Badenhorst (School of Sport, Exercise and Nutrition)
C.Badenhorst@massey.ac.nz
(09)414 0800

MSc Dietetics Student:
Eliot Fenton
eliofent@gmail.com

Associated Researchers:
Dr Wendy O'Brien (School of Sport, Exercise and Nutrition)
W.J.OBrien@massey.ac.nz
(09) 213 6494

Ethics Committee Approval Statement

This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application 20/37. If you have any concerns about the conduct of this research, please contact Dr Negar Partow, Chair, Massey University Human Ethics Committee: Southern A, telephone 04 801 5799 x 63363, email humanethicsoutha@massey.ac.nz.

Thank you for considering participation in this study

Appendix B: Online questionnaire

An assessment on the prevalence of symptoms of low energy availability & Relative Energy Deficiency

Start of Block: Screening Questionnaire

Prevalence of symptoms of low energy availability and relative energy deficiency study

Thank you for your interest in the study investigating energy availability in track specialist athletes. Before you complete the main survey of the study, for administrative purposes, we ask that you complete the following short screening questionnaire.

	Yes	No
Are you between the ages of 16-35 years?	○	○
Are you proficient in English?	○	○
Have you competed in any of the following track events: 100m, 200m, 400m, 800m, 1500m, 3000m, 5000m, steeplechase, or hurdles over any distances listed above?	○	○
Did you compete in track athletics in one of the above events between 2019 and now?	○	○

Display This Question:

If Thank you for your interest in the study investigating energy availability in track specialist at... = No

Thank you for your interest in the survey. Unfortunately, at this time you are outside of the criteria required for the study.

Skip To: End of Survey If Thank you for your interest in the survey. Unfortunately, at this time you are outside of the cri... Is Displayed

End of Block: Screening Questionnaire

Start of Block: Information sheet

Display This Question:

If Thank you for your interest in the study investigating energy availability in track specialist at... [Yes] (Count) = 4

Thank you for completing the screening; you are eligible for the study. Please carefully read the following Information Sheet to decide whether or not you wish to participate in the study.

We would like to invite you to participate in this study investigating low energy availability and Relative Energy Deficiency in Sport (RED-S) syndrome in track athletes. This study is being led by Dr Claire Badenhorst in conjunction with MSc (Dietetics) student Eliot Fenton and Dr Wendy O'Brien, all from the School of Sport, Exercise and Nutrition at Massey University, Auckland, New Zealand.

About the project

Energy availability is the difference between the energy we get from food and the energy we expend during exercise. The remaining energy is utilised by the body to maintain normal physiological functioning. A deficit in available energy is termed low energy availability (LEA) and is considered the underlying contributor to Relative Energy Deficiency in Sport (RED-S) syndrome in athletes. RED-S can result in a number of negative health and performance consequences including declines in bone health, increased injury risk, poor reaction times and declines in muscle strength. While behaviours and risk factors associated with low energy availability have been investigated in endurance and team sport settings, the implications of RED-S in track specialists is currently unknown. Therefore, the aim of the study is to investigate the prevalence, risk factors and performance outcomes of RED-S and LEA in male and female track running athletes, in New Zealand.

What is going to happen?

If you decide to take part in this study after you have read and had time to consider the information contained in this information sheet, you will be asked to complete series of online questionnaires: these questionnaires will cover sleep, injury, health and mental well-being and symptoms associated with RED-S. You will be free to complete these questionnaires in private and at a time convenient to you.

You will also be asked to attend the Massey University Sport and Exercise Lab, Albany to complete the following:

Body composition analysis: initially through Bioelectrical Impedance Analysis scales (BIA) and then later via skinfolds according to established protocols (ISAK guidelines). Both of these assessments will be conducted in a private room

Resting metabolic rate

Reaction time and neuro-cognitive functioning via Stroop test

Knee muscle maximal strength and knee muscle endurance

The measurements conducted at the Massey University Sport and Exercise Lab will be undertaken between 7-10 am, requiring a total time of around 90 minutes. Athletes who are currently injured are invited to complete any aspects of the study that will not aggravate their injury.

Data Management

The data will be used only for the purposes of this project and no individual will be identified. Only the investigators and administrators of the study will have access to personal information and this will be kept secure and strictly confidential. Participants will be identified only by a study identification number. Results of this project may be published or presented at conferences or seminars and no individual will be able to be identified. At the end of this study the list of participants and their study identification number will be disposed of. Any raw data on which the results of the project depend will be retained in secure storage for 5 years, after which it will be destroyed. A summary of the project findings will be available to all study participants. All participants will be sent this information via email or personal letter.

Participants Rights

You are under no obligation to accept this invitation. Should you choose to participate, you have the right to:

Decline to answer any particular question

Withdraw from the study at any time, even after signing a consent form (if you choose to withdraw you cannot withdraw your data from the analysis after the data collection has been completed)

Ask any questions about the study at any time during participation

Provide information on the understanding that your name will not be used unless you give permission to the researcher

Be given access to a summary of the project findings when it is concluded

What are the benefits and risks of taking part in this study?

There will be no cost to you for any of the procedures or assessments taken as part of this study.

The principle benefit of taking part in this study is that you will contribute to a novel area of research and assist us in increasing our understanding of factors that influence RED-S among track athletes in New Zealand.

There are no personal risks to your health as a result of completing this research.

Project Contacts

If you have any questions regarding this study, please do not hesitate to contact any of the following for assistance:

Principal Researcher:

Dr Claire Badenhorst

School of Sport, Exercise and Nutrition

College of Health

Massey University

c.badenhorst@massey.ac.nz

(09) 231 6410

MSc (Dietetics) Student:

Eliot Fenton

eliofent@gmail.com

Associate Researcher:

Dr Wendy O'Brien (School of Sport, Exercise and Nutrition)

w.j.obrien@massey.ac.nz

(09) 213 6494

Ethics Committee Approval: This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application 20/37. If you have any concerns about the conduct of this research, please contact Dr Negar Partow, Chair, Massey University Human Ethics Committee: Southern A, telephone 04 801 5799 x 63363, email humanethicsoutha@massey.ac.nz.

Thank you for considering participation in this study.

End of Block: Information sheet

Start of Block: Consent

CONSENT FORM FOR STUDY VOLUNTEERS

This consent form will be held for a minimum of five (5) years

I have read the Information Sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I understand that I have the right to withdraw from the study at any time and to decline to answer any particular questions (if I choose to withdraw I cannot withdraw my data from the analysis after the data collection has been completed).

I agree to provide information to the researcher on the understanding that my name will not be used without my permission. (The information will be used for this research and publications arising from this research project).

I agree to participate in this study under the conditions set out in the information sheet.

○ Yes

○ No

Skip To: End of Survey If CONSENT FORM FOR STUDY VOLUNTEERS This consent form will be held for a minimum of five (5) years... = No

To confirm your agreement to participant in the study please enter your name and today's date.

Name:

____

Date:

____

End of Block: Consent

Start of Block: Demographics

Please enter your participant ID number or initials

____

What is your age (in years)?

____

What is your sex?

- ○ Male
- ○ Female

Are you currently taking any forms of medication or supplement? Please provide details below.

____

Do you smoke?

- ◯ Yes
- ◯ No

Which ethnic group do you belong to? Please tick whichever applies to you (you may tick more than one box)

- ☐ New Zealand European
- ☐ Maori
- ☐ Samoan
- ☐ Cook Island Maori
- ☐ Tongan
- ☐ Niuean
- ☐ Chinese
- ☐ Indian
- ☐ Other: Please specify ____

What is your first language?

____

What level of competition did you compete in during the 2019 season? Please choose the options that best defines your level of competition (you may choose more than one).

- ▢ Local/community
- ▢ National
- ▢ International
- ▢ Elite age grouper
- ▢ Professional

What is your City of residence in New Zealand?

____

End of Block: Demographics

Start of Block: Illness History

How frequently do you get sick?

- ◯ More than 4 times a year
- ◯ 2-3 times a year
- ◯ I only get sick once a year
- ◯ I haven't been sick in the last year

Have you had any absences from training, or participation in competition, due to illness in the last 12 months?

- ◯ No, none at all
- ◯ Yes, once or twice
- ◯ Yes, three or four times
- ◯ Yes, five or more times

Display This Question:

If Have you had any absences from training, or participation in competition, due to illness in the l... != No, none at all

How many days in total were you absent from training or participation in competition during these illness periods in the last year?

○ 1-7 days

○ 8-14 days

○ 15 -21 days

○ 22 days or more

When you are sick, what sickness are you likely to get? You may select more than one options from the list below.

▢ Upper respiratory tract infection

▢ Common cold

▢ Flu

▢ Gastrointestinal upset

▢ Other, please provide details ____

End of Block: Illness History

Start of Block: Bone Health

Have you ever had a stress fracture as a result of participation in your sport?

○ Yes

○ No

Display This Question:

If Have you ever had a stress fracture as a result of participation in your sport? = Yes

How many stress fractures have you had during your athletic/running career?

____

Display This Question:

If Have you ever had a stress fracture as a result of participation in your sport? = Yes

Please select the location of your previous stress fracture (you may select more than one option)

▢ Foot/Meta-tarsal bones

▢ Tibia

▢ Fibula

▢ Femur

▢ Sacrum

▢ Other ____

End of Block: Bone Health

Start of Block: Endocrine, haematological and CV health:

Have you ever received an abnormal thyroid function blood test?

○ Yes

○ No

Display This Question:

If Have you ever received an abnormal thyroid function blood test? = Yes

Please provide details about your blood test results.

____

____

____

____

____

Page Break

Have you ever been diagnosed with iron deficiency or iron deficiency anaemia?

- ◯ Yes, iron deficiency
- ◯ Yes, iron deficiency anaemia
- ◯ No

Skip To: Q20 If Have you ever been diagnosed with iron deficiency or iron deficiency anaemia? = No

Display This Question:

If Have you ever been diagnosed with iron deficiency or iron deficiency anaemia? != No

How many times in your athletic career have you been diagnosed with iron deficiency or iron deficiency anaemia?

- ◯ None
- ◯ 1-2
- ◯ 3 or more (please provide number) ____

Display This Question:

If How many times in your athletic career have you been diagnosed with iron deficiency or iron defic... != None

Who provided the diagnosis of your iron deficiency or iron deficiency anaemia?

____

____

____

____

____

Page Break

Do you suffer or have you ever suffered from any acute or chronic illness which may affect your iron status?

◯ Yes

◯ No

Display This Question:

If Do you suffer or have you ever suffered from any acute or chronic illness which may affect your i... = Yes

Please provide details on who provided the diagnosis.

____

____

____

____

____

Page Break

Have you ever been treated for iron deficiency or iron deficiency anaemia?

◯ Yes

◯ No

Display This Question:

If Have you ever been treated for iron deficiency or iron deficiency anaemia? = Yes

Please provide details on the treatment type and duration or any other relevant details

____

____

____

____

____

Page Break

Do you have or have you had any medical condition resulting in blood loss? Yes

◯ No

Display This Question:

If Do you have or have you had any medical condition resulting in blood loss? = Yes

Please provide details on this condition

____

____

____

____

____

Page Break

Have you ever experienced abnormal bruising or increased ease of bruising?

◯ Yes

◯ No

Display This Question:

If Have you ever experienced abnormal bruising or increased ease of bruising? = Yes

Please provide any details about your problems with bruising.

____

____

____

____

____

End of Block: Endocrine, haematological and CV health:

Start of Block: Heart health

Have you ever passed out or nearly passed out during or after exercise?Yes

○ No

Have you ever had discomfort, pain, tightness, or pressure in your chest during exercise?

○ Yes

○ No

Does your heart ever race, flutter in your chest, or skip beats (irregular beats) during exercise?

○ Yes

○ No

Has a doctor ever told you that you have a heart problem?

○ Yes

○ No

Has a doctor ever required a test for your heart? For example, electrocardiography (ECG) or echocardiograph.

○ Yes

○ No

Do you get light-headed or have shorter breath than your friends during exercise?

- ◯ Yes
- ◯ No

Have you ever had a seizure?

- ◯ Yes
- ◯ No

Has any family member or relative died of heart problems or had an unexpected or unexplained sudden death before age 35 years?

- ◯ Yes
- ◯ No

Does anyone in your family have a genetic heart problem?

- ◯ Yes
- ◯ No

Has anyone in your family had a pacemaker or implanted defibrillator before age 35 years?

- ◯ Yes
- ◯ No

Have you or has anyone in your family been diagnosed with hypertension (high blood pressure)?

- Yes
- No

Have you or has anyone in your family been diagnosed with hypotension (low blood pressure)?

- Yes
- No

Have you or has anyone in your family been diagnosed with high cholesterol? Yes

- No

End of Block: Heart health

Start of Block: Athlete Sleep Behaviour Questionnaire

For each of the following phrases, please select the response that most accurately reflects your behaviour over the last month (30 days).

	Never	Rarely	Sometimes	Frequently	Always
I take afternoon naps lasting two or more hours	○	○	○	○	○
I use stimulants when I train/compete (e.g caffeine)	○	○	○	○	○
I exercise (train or compete) late at night (after 7 pm)	○	○	○	○	○
I consume alcohol within 4 hours of going to bed	○	○	○	○	○
I go to bed at different times each night (more than ±1 hour variation)	○	○	○	○	○
I go to bed feeling thirsty	○	○	○	○	○
I go to bed with sore muscles	○	○	○	○	○

I use light-emitting technology in the hour leading up to bedtime (e.g laptop, phone, television, video games)	○	○	○	○	○
I think, plan and worry about my sporting performance when I am in bed	○	○	○	○	○
I think, plan and worry about issues not related to my sport when I am in bed	○	○	○	○	○
I use sleeping pills/tablets to help me sleep	○	○	○	○	○
I wake to go to the bathroom more than once per night	○	○	○	○	○

I wake myself and/or my bed partner with my snoring	○	○	○	○	○
I wake myself and/or my bed partner with my muscle twitching	○	○	○	○	○
I get up at different times each morning (more than ±1 hour variation)	○	○	○	○	○
At home, I sleep in a less than ideal environment (e.g too light, too noisy, uncomfortable bed/pillow, too hot/cold)	○	○	○	○	○
I sleep in foreign environments (e.g hotel rooms)	○	○	○	○	○

Travel gets in the way of building a consistent sleep-wake routine	○	○	○	○	○

End of Block: Athlete Sleep Behaviour Questionnaire

Start of Block: POMS

For each point below, please select the response that best describes how feel right now.

	Not at all	A little	Moderately	Quite alot	Extremely
Tense	○	○	○	○	○
Angry	○	○	○	○	○
Worn out	○	○	○	○	○
Unhappy	○	○	○	○	○
Proud	○	○	○	○	○
Lively	○	○	○	○	○
Confused	○	○	○	○	○
Sad	○	○	○	○	○
Active	○	○	○	○	○
On-edge	○	○	○	○	○
Grouchy	○	○	○	○	○
Ashamed	○	○	○	○	○
Energetic	○	○	○	○	○
Hopeless	○	○	○	○	○
Uneasy	○	○	○	○	○
Restless	○	○	○	○	○
Unable to concentrate	○	○	○	○	○

Fatigued	○	○	○	○	○
Competent	○	○	○	○	○
Annoyed	○	○	○	○	○
Discouraged	○	○	○	○	○
Resentful	○	○	○	○	○
Nervous	○	○	○	○	○
Miserable	○	○	○	○	○

End of Block: POMS

Start of Block: LEAF-Q

Display This Question:

If What is your sex? = Female

Have you had absences from your training, or participation in competitions during the last year due to injuries?

○ No, not at all

○ Yes, once or twice

○ Yes, 3 or 4 times

○ Yes, 5 times or more

Display This Question:

If What is your sex? = Female

And Have you had absences from your training, or participation in competitions during the last year d... != No, not at all

How many days absence from training or participation in competition due to injuries have you had in the last year?

- ◯ 1-7 days
- ◯ 8-14 days
- ◯ 15-21 days
- ◯ 22 days or more

Display This Question:

If What is your sex? = Female

What kind of injuries have you had in the last 12 months? You may select more than one from the list below.

- ▢ Stress fracture/reaction
- ▢ Ligament sprain
- ▢ Muscle strain (please provide details of grading if known) ________________
- ▢ Neural injury (disk etc)
- ▢ Muscle tear (please specify grading if known)
- ▢ Injury via accident (comment on accident)
- ▢ Headaches/migraine
- ▢ Posture related injury (please provide details) ________________
- ▢ Other (Comment) ________________

Page Break

Display This Question:

If What is your sex? = Female

Do you feel gaseous or bloated in the abdomen which cannot be related to your period or pre-menstruation symptoms?

- ◯ Yes, several times a day
- ◯ Yes, several times a week
- ◯ Yes, once or twice a week or more seldom
- ◯ Rarely or never

Display This Question:

If What is your sex? = Female

Do you get cramps or stomach ache which cannot be related to your menstruation?

- ◯ Yes, several times a day
- ◯ Yes, several times a week
- ◯ Yes, once or twice a week or more seldom
- ◯ Rarely or never

Display This Question:

If What is your sex? = Female

How often do you have bowel movements on average?

- Several times a day
- Once a day
- Every second day
- Twice a week
- Once a week or more rarely

Display This Question:

If What is your sex? = Female

How would you describe your normal stool?

- Normal (soft)
- Diarrhoea-like (watery)
- Hard and dry

Page Break

Display This Question:

If What is your sex? = Female

Do you use oral contraceptives?

- Yes
- No

Display This Question:

If Do you use oral contraceptives? = Yes

And What is your sex? = Female

Why do you use oral contraceptives?

- ◯ Contraception
- ◯ Reduction of menstruation pains
- ◯ Reduction of bleeding
- ◯ To regulate the menstrual cycle in relation to performances etc
- ◯ Otherwise menstruation stops
- ◯ Other ____

Display This Question:

If Do you use oral contraceptives? = No

Have you previously used oral contraceptives?

- ◯ Yes
- ◯ No

Display This Question:

If Have you previously used oral contraceptives? = Yes

When and for how long?

____

Display This Question:

If What is your sex? = Female

Do you use or have you used any other kind of hormonal contraceptives? (e.g. hormonal implant or coil)

○ Yes

○ No

Display This Question:

If Do you use or have you used any other kind of hormonal contraceptives? (e.g. hormonal implant or... = Yes

What other kind of hormonal contraceptives do you use? (select as many as apply to you)

☐ Hormonal patches

☐ Hormonal ring

☐ Hormonal coil

☐ Hormonal implant

☐ Other ____

Display This Question:

If What is your sex? = Female

How old were when you had your first period?

○ 11 years or younger

○ 12-14 years

○ 15 years or older

○ I don’t remember

○ I have never naturally menstruated

Skip To: End of Block If How old were when you had your first period? = I have never naturally menstruated

Display This Question:

If How old were when you had your first period? = 11 years or younger

Or How old were when you had your first period? = 12-14 years

Or How old were when you had your first period? = 15 years or older

Or How old were when you had your first period? = I don't remember

Did your first menstruation come naturally (by itself)?

- ○ Yes
- ○ No
- ○ I don't remember

Display This Question:

If Did your first menstruation come naturally (by itself)? = No

What kind of treatment was used to start your menstrual cycle?

- ○ Hormonal treatment
- ○ Weight gain
- ○ Reduced amount of exercise
- ○ Other ____

Display This Question:

If What is your sex? = Female

Do you have normal menstruation?

- ◯ Yes
- ◯ No
- ◯ I don't know

Display This Question:

If Do you have normal menstruation? = Yes

When was your last period?

- ◯ 0-4 weeks ago
- ◯ 1-2 months ago
- ◯ 3-4 months ago
- ◯ 5 months ago or more

Display This Question:

If Do you have normal menstruation? = Yes

Are your periods regular? (i.e. every 28th to 34th day)

- ◯ Yes, most of the time
- ◯ No, mostly not

Display This Question:

If Are your periods regular? (i.e. every 28th to 34th day) = Yes, most of the time

For how many days do you normally bleed?

- ○ 1-2 days
- ○ 3-4 days
- ○ 5-6 days
- ○ 7-8 days
- ○ 9 days or more

Display This Question:

If Do you have normal menstruation? = Yes

Have you ever had problems with heavy menstrual bleeding?

- ○ Yes
- ○ No

Display This Question:

If Do you have normal menstruation? = Yes

How many periods have you had during the last year?

- ○ 12 or more
- ○ 9-11
- ○ 6-8
- ○ 3-5
- ○ 0-2

Display This Question:

If Do you have normal menstruation? = No

Or Do you have normal menstruation? = I don't know

When did you have your last period?

- ○ 2-3 months ago
- ○ 4-5 months ago
- ○ 6 months ago or more
- ○ I'm pregnant and therefore do not menstruate

Display This Question:

If What is your sex? = Female

Have your periods ever stopped for 3 consecutive months or longer (besides pregnancy)?

- ○ No, never
- ○ Yes, it has happened before
- ○ Yes, that's the situation now

Display This Question:

If What is your sex? = Female

Do you experience any changes in your menstruation when you increase your exercise intensity, frequency or duration?

- ○ Yes
- ○ No

Display This Question:

If Do you experience any changes in your menstruation when you increase your exercise intensity, fre... = Yes

How does your menstruation change when you increase your exercise intensity, frequency or duration? (Please select as many options as apply to you)

- ☐ I bleed less
- ☐ I bleed fewer days
- ☐ My menstruations stops
- ☐ I bleed more
- ☐ I bleed more days

End of Block: LEAF-Q

Start of Block: MEAT-Q

Display This Question:

If What is your sex? = Male

Have you had any absences from training, or participation in training due to injury in the last 12 months?

- ○ Not at all
- ○ Yes, once or twice
- ○ Yes, three or four times
- ○ Yes, five or more times

Display This Question:

If Have you had any absences from training, or participation in training due to injury in the last 1... = Yes, once or twice

Or Have you had any absences from training, or participation in training due to injury in the last 1... = Yes, three or four times

Or Have you had any absences from training, or participation in training due to injury in the last 1... = Yes, five or more times

How many days were you absent from training or participation in competition during these injury periods in the last year?

- ◯ 1-7 days
- ◯ 8-14 days
- ◯ 15-21 days
- ◯ 22 days or more

Display This Question:

If Have you had any absences from training, or participation in training due to injury in the last 1... = Yes, once or twice

Or Have you had any absences from training, or participation in training due to injury in the last 1... = Yes, three or four times

Or Have you had any absences from training, or participation in training due to injury in the last 1... = Yes, five or more times

What kind of injuries have you had in the last 12 months? You may select more than one from the list below.

- ▢ Stress fracture/reaction
- ▢ Ligament sprain
- ▢ Muscle strain
- ▢ Neural injury (disk etc)
- ▢ Muscle tear (please specify grading if known) ________________
- ▢ Injury via accident (comment on accident) ________________
- ▢ Headaches/migraine
- ▢ Posture related injury (please provide details) ________________
- ▢ Other (Comment) ________________

Display This Question:

If What is your sex? = Male

Do you ever feel gaseous or bloated?

- ○ Yes, constantly
- ○ Yes, several times a day
- ○ Yes, several times a week
- ○ Yes, once or twice a week or more seldom
- ○ Rarely

Display This Question:

If What is your sex? = Male

How often do you have bowel movements?

- Several times a day
- Once a day
- Every second day
- Twice a week
- Once a week or rarely

Display This Question:

If What is your sex? = Male

How would you describe your normal stool using the Bristols stool chart below?

- Type 1
- Type 2
- Type 3
- Type 4
- Type 5
- Type 6
- Type 7

Display This Question:

If What is your sex? = Male

Do you ever experience an upset stomach or an increased need to pass a bowel movement while running or other physical activities/training?

- Yes, always
- Yes, more than twice a week
- Yes, occasionally or once a week
- Yes, but I have never had to stop running
- No, never

Display This Question:

If Do you ever experience an upset stomach or an increased need to pass a bowel movement while runni... = Yes, always

Or Do you ever experience an upset stomach or an increased need to pass a bowel movement while runni... = Yes, more than twice a week

Or Do you ever experience an upset stomach or an increased need to pass a bowel movement while runni... = Yes, occasionally or once a week

Or Do you ever experience an upset stomach or an increased need to pass a bowel movement while runni... = Yes, but I have never had to stop running

How frequently would you suffer from an upset stomach or an increased need to pass a bowel movements while running or during other physical activities/training?

- Everytime
- Occasionally (2-3 runs per week)
- Rarely (
- Never

Page Break

Display This Question:

If What is your sex? = Male

The next series of questions will focus on physiological symptoms associated with insufficient energy intake. These questions will be focused on reproductive function and your personal perception of your libido and reproductive function in the last month. We appreciate that you are taking time to complete the survey and ask that you answer the questions as honestly as possible to ensure we get accurate results. We would like to re-emphasise that all data is treated as confidential and your responses will not be individually identifiable to the research team or in reports that come from the data we collect. Your confidentiality is a priority to this research study.

Display This Question:

If What is your sex? = Male

In the last month, have you noticed a lack in energy throughout the day?

- ◯ Yes
- ◯ Maybe
- ◯ No

Display This Question:

If What is your sex? = Male

In the last month, have you noticed a decline in strength and/or endurance during training?

- ◯ Yes
- ◯ Maybe
- ◯ No

Display This Question:

If What is your sex? = Male

In the last month, have you noticed a decline in your recovery after training or in your general feeling of fitness?

- ○ Yes
- ○ Maybe
- ○ No

Display This Question:

If What is your sex? = Male

In the last month, have you noticed that it is harder to maintain concentration at work or while having a conversation?

- ○ Yes
- ○ Maybe
- ○ No

Display This Question:

If What is your sex? = Male

In the last month, have you noticed an increased need for sleep? (increased need for naps, more sleep, or feeling like you are not getting enough sleep)

- ○ Yes
- ○ Maybe
- ○ No

Display This Question:

If What is your sex? = Male

In the last month, have you noticed that your erections are less strong?

- ◯ Yes
- ◯ Maybe
- ◯ No

Display This Question:

If What is your sex? = Male

In the last month, how often would you have liked to engage in sexual activity with your partner or another person?

- ◯ A lot
- ◯ Minimal
- ◯ None

Display This Question:

If What is your sex? = Male

In the last month, how often have you had sexual thoughts involving your partner or another person?

- ◯ A lot
- ◯ Minimal
- ◯ None

Display This Question:

If What is your sex? = Male

In the last month, has your desire to engage in sexual activity with your partner or another person been? (ie do you have a strong response or sexual thoughts when see your partner or an attractive person)

◯ Yes

◯ Maybe

◯ No

Display This Question:

If What is your sex? = Male

In the last month, how often would you have liked to engage in sexual activity or behaviour with yourself?

◯ A lot

◯ Minimal

◯ None

Display This Question:

If What is your sex? = Male

In the last month, would you that consider your desire to engage in sexual activity or behaviour with yourself has been?

◯ Yes

◯ Maybe

◯ No

Display This Question:

If What is your sex? = Male

In the last month, would you consider it important for you to fulfil your sexual desire with yourself, your partner or another person?

- ◯ Yes
- ◯ Maybe
- ◯ No

Display This Question:

If What is your sex? = Male

In the last month, and compared to other people your age, how would you rate your desire to behave sexually with your partner or another person?

- ◯ Good
- ◯ Ok
- ◯ Not good

Display This Question:

If What is your sex? = Male

In the last month, and compared to other people your age, how would you rate your desire to behave sexually with yourself?

- ◯ Good
- ◯ Ok
- ◯ Not good

Display This Question:

If What is your sex? = Male

In the last month, how long could you go comfortably without having sexual activity of some kind?

- 1 to 3 days
- 1-2 weeks
- > 3 weeks

End of Block: MEAT-Q

Start of Block: EDE-Q

The following questions are concerned with the past four weeks (28 days) only. Please read each question carefully and answer all of the questions.

On how many of the past 28 days....

	No days	1-5 days	6-12 days	13-15 days	16-22 days	23-27 days	Everyday
Have you been deliberately trying to limit the amount of food you eat to influence your shape or weight (whether or not you have succeeded)?	○	○	○	○	○	○	○
Have you gone for long periods of time (8 waking hours or more) without eating anything at all in order to influence your shape or weight?	○	○	○	○	○	○	○

Have you tried to exclude from your diet any foods that you like, in order to influence your shape or weight (whether or not you have succeeded)?	○	○	○	○	○	○	○
Have you tried to follow definite rules regarding your eating (for example, a calorie limit) in order to influence your shape or weight (whether or not you have succeeded)?	○	○	○	○	○	○	○

Have you had a definite desire to have an empty stomach with the aim of influencing your shape or weight?	○	○	○	○	○	○	○
Have you had a definite desire to have a totally flat stomach?	○	○	○	○	○	○	○

Has thinking about food, eating or calories made it very difficult to concentrate on things you are interested in (for example, working, following a conversation, or reading)?	○	○	○	○	○	○	○
Has thinking about shape or weight made it very difficult to concentrate on things you are interested in (for example, working, following a conversation, or reading)?	○	○	○	○	○	○	○

Have you had a definite fear of losing control over eating?	○	○	○	○	○	○	○
Have you had a definite fear that you might gain weight?	○	○	○	○	○	○	○
Have you felt fat?	○	○	○	○	○	○	○
Have you had a strong desire to lose weight?	○	○	○	○	○	○	○

Page Break

Over the past 28 days....

	No days	1-5 days	6-12 days	13-15 days	16-22 days	23-27 days	Everyday
How many times have you eaten what other people would regards as an unusually large amount of food (given the circumstances)?	○	○	○	○	○	○	○
...On how many of these times did you have a sense of having lost control over your eating (at the time you were eating)?	○	○	○	○	○	○	○

...On how many DAYS have such episodes of overeating occurred (i.e. you have eaten an unusually large amount of food and have had a sense of loss of control at the time)?	○	○	○	○	○	○	○
How many times have you made yourself sick (vomit) as a means of controlling your shape or weight?	○	○	○	○	○	○	○
How many times have you taken laxatives as a means of controlling your shape or weight?	○	○	○	○	○	○	○

How many times have you exercised in a “driven” or “compulsive” way as a means of controlling your weight, shape or amount of fat, or to burn off calories?	○	○	○	○	○	○	○
......On how many days have you eaten in secret (ie, furtively)? … Do not count episodes of binge eating.	○	○	○	○	○	○	○

On what proportion of the times that you have eaten have you felt guilty (felt that you've done wrong) because of its effect on your shape or weight? … Do not count episodes of binge eating.	○	○	○	○	○	○	○

Page Break

Please fill in the appropriate number in the boxes on the right. Remember the questions only refer to the past four weeks (28 days). Over the past four weeks (28 days)......

On how many of these times did you have a sense of having lost control over your eating (at the time you were eating)?

Over the past 28 days, on how many DAYS have such episodes of overeating occurred (i.e. you have eaten an unusually large amount of food and have had a sense of loss of control at the time)?

Over the past 28 days, how many times have you made yourself sick (vomit) as a means of controlling your shape or weight?

Over the past 28 days, how many times have you taken laxatives as a means of controlling your shape or weight?

Over the past 28 days, how many times have you exercised in a “driven” or “compulsive” way as a means of controlling your weight, shape or amount of fat, or to burn off calories?

Please select the appropriate box. Please note that for these questions the term "binge eating" means eating what others would regard as an unusually large amount of food for the circumstances, accompanied by a sense of having lost control over eating.

	No days	1-5 days	6-12 days	13-15 days	16-22 days	23-27 days	Everyday
Over the past 28 days, on how many days have you eaten in secret (ie, furtively)? ..... Do not count episodes of binge eating	○	○	○	○	○	○	○

	None of the time	A few times	Les than half	Half of the time	More than half	Most of the time	Every time
On what proportion of the times that you have eaten have you felt guilty (felt that you've done wrong) because of its effect on your shape or weight?... Do not count episodes of binge eating	○	○	○	○	○	○	○

	0	1	2	3	4	5	6
Over the past 28 days, how concerned have you been about other people seeing you eat?... Do not count episodes of binge eating.	○	○	○	○	○	○	○

Page Break

Please circle the appropriate number on the right. Remember that the questions only refer to the past four weeks

(28 days).

On how many over the past 28 days........

	0	1	2	3	4	5	6
Has your weight influenced how you think about (judge) yourself as a person?	○	○	○	○	○	○	○
Has your shape influenced how you think about (judge) yourself as a person	○	○	○	○	○	○	○
How much would it have upset you if you had been asked to weigh yourself once a week (no more, or less, often) for the next four weeks?	○	○	○	○	○	○	○

How dissatisfied have you been with your weight?	○	○	○	○	○	○	○
How dissatisfied have you been with your shape?	○	○	○	○	○	○	○
How uncomfortable have you felt seeing your body (for example, seeing your shape in the mirror, in a shop window reflection, while undressing or taking a bath or shower)?	○	○	○	○	○	○	○

How uncomfortable have you felt about others seeing your shape or figure (for example, in communal changing rooms, when swimming, or wearing tight clothes)?	○	○	○	○	○	○	○

Page Break

Please select the appropriate number on the right. Remember that the questions only refer to the past four weeks

(28 days).

How many over the last 28 days.............

	0	1	2	3	4	5	6
Has weight influenced how you think about (judge) yourself as a person?	○	○	○	○	○	○	○
Has your shape influenced how you think about (judge) yourself as a person	○	○	○	○	○	○	○
How much would it have upset you if you had been asked to weigh yourself once a week (no more, or less often) for the next four weeks)?	○	○	○	○	○	○	○

How dissatisfied have you been with your weight?	○	○	○	○	○	○	○
How dissatisfied have you been with your shape?	○	○	○	○	○	○	○
How uncomfortable have you felt seeing your body (for example, seeing your shape in the mirror, in a shop window reflection, while undressing or taking a bath or shower)?	○	○	○	○	○	○	○

Page Break

What is your weight (kg) at present? (Please give your best estimate):

What is your height (cm)? (Please give your best estimate):

____

End of Block: EDE-Q

Start of Block: Exercise dependence scale

Using the scale provided below, please complete the following questions as honestly as possible. The questions refer to current exercise beliefs and behaviors that have occurred in the past 3 months.

	Never	Sometimes	About half the time	Most of the time	Always
I exercise to avoid feeling irritable					
I exercise despite recurring physical problems					
I continually increase my exercise intensity to achieve the desired effects/benefits					
I am unable to reduce how long I exercise					
I would rather exercise than spend time with family/friends					
I spend a lot of time exercising					
I exercise longer than I intend					

I exercise to avoid feeling anxious	○	○	○	○	○
I exercise when injured	○	○	○	○	○
I continually increase my exercise frequency to achieve the desired effects/benefits	○	○	○	○	○
I am unable to reduce how often I exercise	○	○	○	○	○
I think about exercise when I should be concentrating on school/work	○	○	○	○	○
I spend most of my free time exercising	○	○	○	○	○
I exercise longer than I expect	○	○	○	○	○

I exercise to avoid feeling tense	○	○	○	○	○
I exercise despite persistent physical problems	○	○	○	○	○
I continually increase my exercise duration to achieve the desired effects/benefits	○	○	○	○	○
I am unable to reduce how intense I exercise	○	○	○	○	○
I choose to exercise so that I can get out of spending time with family/friends	○	○	○	○	○
A great deal of my time is spent exercising	○	○	○	○	○

I exercise longer than I plan	○	○	○	○	○

End of Block: Exercise dependence scale

Start of Block: Thank you

Display This Question:

If Thank you for your interest in the study investigating energy availability in track specialist at... [No] (Count) > 1

Thank you for your interest in the survey. At this time we recognise that you are outside of the eligibility criteria we set for the survey. We do appreciate your time in completing the screening questions.

Display This Question:

If CONSENT FORM FOR STUDY VOLUNTEERS This consent form will be held for a minimum of five (5) years... = No

Thank you for your time in considering the study

Thank you for taking time to complete the survey. We would like to follow up with details on a food and training diary to support the findings from this survey. This will be completed online. If you are able to provide an email address so that we can contact you it would be greatly appreciated.

____

End of Block: Thank you