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**Screening for risk of Low Energy Availability in elite female
netball athletes and the prevalence of injury**

A thesis

submitted in fulfilment

of the requirements for the degree

of

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at

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Abstract

Low Energy Availability (LEA) is a condition commonly seen in female athletes, often as a consequence of insufficient dietary intake relative to energy expenditure, resulting in an energy deficit. A negative energy balance can severely impact normal physiological functions, often causing the body to downregulate to conserve energy as a means to survive. LEA poses a significant health risk, which has been associated with a plethora of unfavourable health and performance outcomes such as; reproductive function, bone health, gastrointestinal function, cardiovascular health, immune function and psychological impairment. Until now, limited research has been available for the prevalence of LEA in the team sport population, as most previous studies have concentrated on endurance and/or individual sport athletes. As highlighted in the literature review in the first part of this thesis, the prevalence of LEA ranges from 2-100% in various sports and disciplines, however the few studies to investigate the prevalence of LEA in team sport athletes have found reasonably high rates of LEA present. The associated health outcomes are continuously emerging in research, alongside the multiple measures to screen and diagnosis for LEA, which are explained in the literature review. The second part of this thesis comprises of an original study investigating the prevalence of LEA within elite female netball athletes in New Zealand. Fifty-three elite netballers volunteered to participate in this study and were required to complete an adapted version of the Low Energy Availability in Females questionnaire (LEAF-Q) to identify risk of LEA. Analysis found a concerning prevalence of 53% of participants considered 'at-risk' of developing LEA, with additional findings discovering 85.7% of the 'at-risk' athletes had sustained an injury within the last 12 months. The final section of this thesis summarises the overall findings of the thesis, as well as providing practical applications, and highlighting direction for future research in this area.

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Thesis Organisation

The current thesis consists of three chapters. Chapter One presents a review of the literature on LEA, the health outcomes of LEA, the association of LEA and injuries and the prevalence of LEA in various populations. Chapter Two comprises of an original study investigating the prevalence of LEA in elite female netball athletes via the Low Energy Availability in Females Questionnaire (LEAF-Q). This chapter is presented in the style of an individual journal article in its submitted format and consequently some information throughout the thesis may be repeated. Chapter Three provides a summary of the overall findings of both the literature review and original study, along with practical applications, limitations and recommendations for future research.

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Abbreviations

ASCM	American College of Sports Medicine
BMD	Bone mineral density
BSI	Bone stress injuries
CI	Confidence Interval
DE	Disordered eating
EA	Energy availability
EAMD	Exercise-associated menstrual disturbances
ED	Eating disorder
EEE	Exercise energy expenditure
EI	Energy intake
Ex-HRT	Exercise + Hormone replacement therapy
FAT	Female Athlete Triad
FFM	Fat free mass
FHA	Functional hypothalamic amenorrhoea
HRT	Hormone replacement therapy
IOC	International Olympic Committee
LCSA	Lean tissue cross sectional area
LEA	Low energy availability
LEAF-Q	Low Energy Availability in Female's Questionnaire
LPD	Luteal phase deficiency
MHR	Maximum heart rate
OR	Odds ratio
RED-S	Relative Energy Deficiency in Sport
SFHA	Secondary functional hypothalamic amenorrhea

SD	Standard deviation
T ₃	Triiodothyronine
TEE	Total energy expenditure

Chapter One – Literature Review

Introduction

Participation in sport, physical activity and exercise is well known to provide desirable health benefits and is widely promoted in previous research as a key element of a healthy lifestyle (Gibbs et al., 2013; Nattiv et al., 2007). Whilst regular participation in physical activity can promote positive effects on one's health, there are circumstances where individuals may expose themselves to negative health issues as a result of inadequate energy intake, thus having insufficient energy to carry out the demands of physiological functioning and training (Kroshus et al., 2018). Elite athletes are continuously exposed to strenuous training demands in a bid to be the fastest and strongest in their respective sporting code, which may mean they are more susceptible to experiencing symptoms and the impacts of Low Energy Availability (LEA) often due to excessive exercise in conjunction with inadequate caloric intake (Lis et al., 2015). LEA is typically described as a condition observed most commonly in females (though also observed in males), which can negatively influence areas such as (but not limited to) bone health, cardiovascular function, menstrual function, gastrointestinal function, and mental health (Loucks et al., 2011; Slater, 2015). LEA is typically caused by the reduction of dietary intake and/or through the increase of energy expended through exercise, essentially creating an energy deficit to the extent where the body is unable to continue regular bodily processes and functioning. When individuals are in a state of LEA for a period of time, the body no longer functions optimally, causing many physiological functions to downregulate to conserve energy as a means to survive (Black et al., 2018).

Much of the recent literature investigating the effects and prevalence of LEA in elite athletes has shown a focus towards individual sports and endurance athletes in particular. However, there is emerging evidence that suggests athletes participating in team sports

are also greatly at risk of developing LEA due to the high intensity, intermittent nature of many team sporting codes (Heaney et al., 2008; Renard et al., 2021). Thus, the importance of investigating elite team sport cohorts who have been excluded from a large majority of previous research in this area is warranted.

Therefore, the objective of this literature review is to provide an overview of the development of the current LEA models, discuss the health and performance outcomes of LEA, the known prevalence in various populations, current assessment and screening tools, coach and physician awareness, as well as the potential link between LEA and rates of injury.

Overview of LEA

Energy availability (EA) is often described as an imbalance between energy intake (EI = total caloric intake per day) and total energy expenditure (TEE = resting energy expenditure and exercise energy expenditure). EA can be visualised as the amount of energy available once exercise energy expenditure (EEE) is accounted for and expressed relative to fat-free mass (FFM), which equates to the amount of energy remaining for the body to process metabolic and physiological functions ($EA = (EI - EEE)/FFM$) (Holtzman & Ackerman, 2019; Loucks et al., 2011). Ideally, energy availability should balance, or slightly exceed resting energy expenditure to allow for normal functioning of the body to continue (Black et al., 2018; Groom, 2019; Javed et al., 2013; Loucks et al., 2011; Loucks et al., 1998). It has been shown that when energy availability is too low, associated physiological mechanisms downregulate to reduce the energy used, to support cellular maintenance including homeostasis, growth, and the activities of daily living (Nattiv et al., 2007; Williams et al., 2019). The compensation of these functions tend to

restore energy balance as a means to survive, however this impairs well-being as a result, triggering a plethora of unfavourable health and performance outcomes (Tornberg Å et al., 2017; Vanheest et al., 2014; Williams et al., 2015). Typically, the physiological functions not necessary for survival such as menstrual function, metabolic rate, immunity and bone health are affected or ceased when in a state of LEA, which is to allow energy for the crucial organs to function (Wasserfurth et al., 2020).

At present, studies have suggested an EA of at least 45 kcal/kg fat free mass (FFM)/day for sedentary women with normal menstrual function, as a threshold to ensure optimal energy availability allowing physiological functions to continue (Melin et al., 2019). An EA of 30-45kcal/kg/FFM is commonly considered as a subclinical EA (Wasserfurth et al., 2020), with those displaying an EA of < 30 kcal/kg FFM/day being classified with clinically low EA. According to Melin and colleagues (2019), even only 5 days with an EA < 30 kcal/kg FFM/day can cause severe physiological functions such as a reduction in blood glucose, which is known as sugar in the bloodstream to supply energy (Burrin & Alberti, 1990), and leptin levels which is a hormone of energy status within the body signalling satiety to the brain (Heini et al., 1998). In addition to lowered blood glucose and leptin levels, other physiological markers commonly affected due to energy deficiency include a decrease in blood pressure, resting metabolic rate and a disruption in hormones including cortisol, ghrelin, insulin and Triiodothyronine (T₃) (Logue et al., 2018). T₃ controls many vital biological processes and is responsible for the regulation of a normal metabolism via the hypothalamic-pituitary-thyroid axis (de Oliveira et al., 2020). The existing research has presented mixed results on the levels of T₃ in different populations (Koehler et al., 2013; Melin et al., 2015; Vanheest et al., 2014), however, the results are indicative of a decrease in T₃ levels in female athletes with menstrual

irregularities (Logue et al., 2018). Additionally, higher levels of cortisol, which is the steroid hormone released in response to stress, have been observed in athletes with menstrual dysfunction compared to eumenorrheic athletes (Melin et al., 2015; Schaal et al., 2017).

With this previous research in mind, individuals who regularly participate in exercise will require an increase in dietary intake to account for the energy expended through exercise. Additionally, individuals who exercise excessively or restrict dietary intake tend to be at higher risk of developing LEA and/or nutrient deficiencies (Logue et al., 2019). It is important to note that while LEA can be influenced by excessive exercise paired with insufficient dietary intake, LEA can also be a result of nutritional restriction alone, in individuals with lower training hours. This concept is shown by Slater (2015), who reported 33.5% of recreational athletes with an average of 8.5 hours of exercise per week, to be 'at-risk' of LEA (Slater, 2015). Nutritional restriction can be intentional or unintentional, with low caloric intake commonly presenting due to factors such as lack of knowledge of appropriate nutrition, lack of time to prepare meals or even loss of appetite due to training (Wasserfurth et al., 2020). The development of deliberate dietary restrictions can begin as unintentional, which may then turn compulsive due to an array of reasons. Body dissatisfaction, nutrition misconceptions and sport specific body image aesthetics are all common reasons towards development of intentional disordered eating (Thein-Nissenbaum et al., 2011; Wasserfurth et al., 2020). LEA and eating restrictions can affect both males and females, within the general population, recreational and club level athletes as well, however, it is known that female athletes are particularly susceptible to developing LEA, with previous research showing that female athletes are 5.4 times more likely to be at risk of LEA when compared to male athletes (Black et al., 2018;

Dolan et al., 2011; Groom, 2019; Heikura et al., 2018; Slater, 2015).

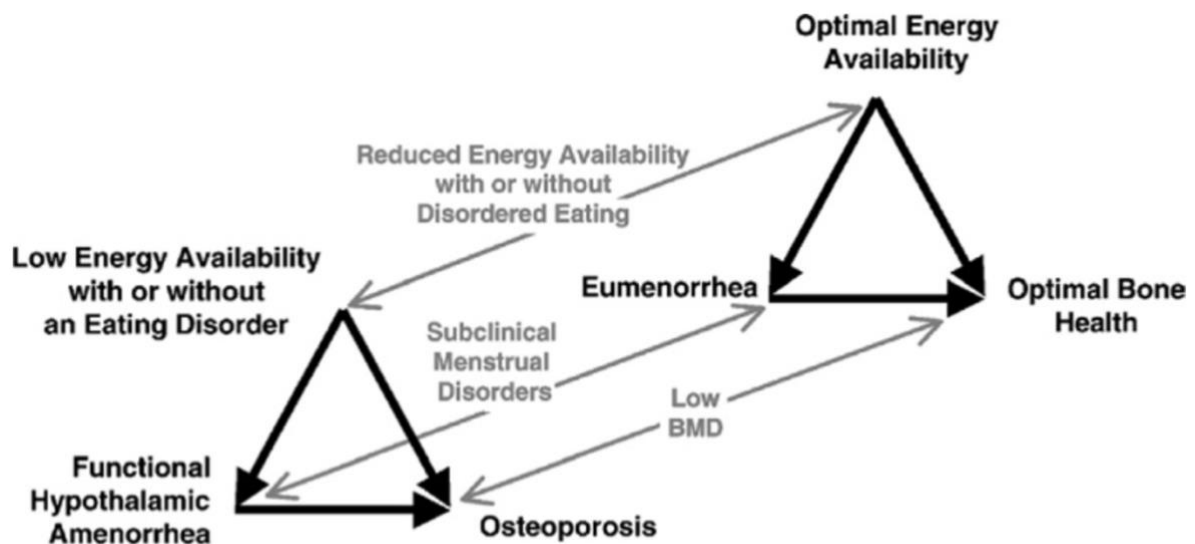
As mentioned previously, LEA is most commonly presented through physical and physiological signs and symptoms, however, it is important to note that the psychological relationship with LEA is bi-directional, and psychological outcomes can either precede LEA or be a result of LEA symptoms. It is thought that athletes may experience pressures to look a certain way or to achieve an 'ideal' body type relevant to their sport, such as ballet dancers and synchronised swimmers (Łagowska & Kapczuk, 2016; Schaal et al., 2017). However, these pressures can be very dangerous and can increase the risk of the development of nutritional deficits/eating disorders and excessive training habits, most commonly seen in athletes who participate in sports emphasising leanness, aesthetics or a certain body type (Heather et al., 2021). Performance pressures may also contribute towards a low energy availability, influenced by the rhetoric that performance may improve if an athlete is thinner or conform to sociocultural ideals of the sport (Warrick et al., 2020). It has therefore been previously advised that monitoring and screening protocols for psychological signs which include but are not limited to; restrictive eating, excessive exercise, extreme performance orientation and self-judgement be implemented alongside physical and physiological monitoring in the overall screening of LEA (Melin et al., 2019).

Development of LEA Models

The early research on LEA and the discovery of menstrual dysfunction in female athletes has been discussed in detail in previous literature reviews and studies (Nattiv et al., 2007; Slater, 2015; Yeager et al., 1993). Concerns arose in the early 1960's surrounding female athletes and the association between exercise and menstrual disturbances (Erdelyi, 1962),

however, it was not until 1980/90's that a collection of research emerged which saw the correlation of disordered eating (low calorie intake and/or restriction which can be intentional or unintentional) (Benson et al., 1996), amenorrhoea (absence of menses) and osteoporosis observed in female athletes (Marcus et al., 1985; Slater, 2015; B. Warren et al., 1990; M. Warren et al., 1986). These areas of concern grew significantly in 1992 when the American College of Sports Medicine (ACSM) convened the term 'the Female Athlete Triad' (FAT), which was defined as the "combination of disordered eating, amenorrhoea and osteoporosis found in physically active women" (Yeager et al., 1993).

Figure 1. Female Athlete Triad updated model

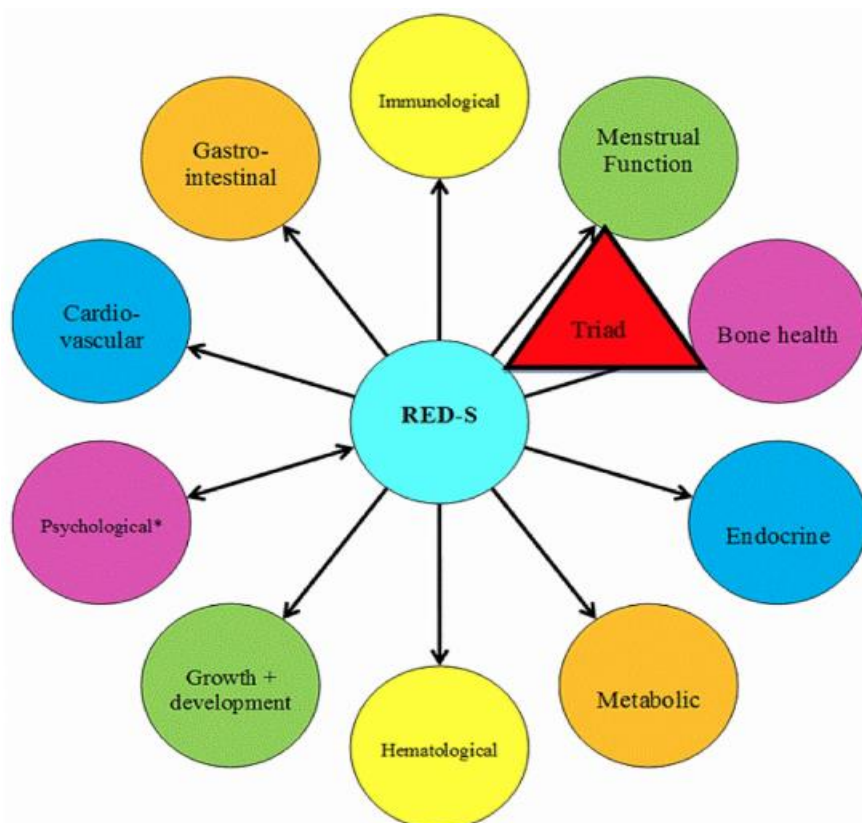


Note. From "American College of Sports Medicine position stand. The female athlete triad" by Nattiv et al., 2007 *Medicine & Science in Sports & Exercise*. 39(10), 1867-1882. Permission pending.

A revision of the FAT by the ACSM was published in 2007, where an updated model was developed as a three-dimension scale (Figure 1), where an individual can fall anywhere between a state of disease (osteoporosis, energy deficiency and/or amenorrhoea) or good health (optimal bone health, normal menstrual cycle and healthy eating habits) (Slater et al., 2017). More recently, the International Olympic Committee developed a new phenomenon in 2014; Relative Energy Deficiency in Sport (RED-S) (Figure 2). The

terminology ‘relative energy deficiency’ is used to define the underlying problem of this syndrome, which is having inadequate levels of energy by fuel to support the plethora of physiological functions that are required for optimal health and performance (Mountjoy et al., 2014). RED-S was a major modification to the FAT, which highlights the expansive range of negative health consequences beyond those described within the Triad, furthermore, recognising that males can suffer from health and performance implications of LEA in addition to females (Mountjoy et al., 2014). The newly developed RED-S concept considers a much broader array of physiological and performance outcomes in athletes, that were previously not recognised by the formerly developed FAT model (Williams et al., 2019).

Figure 2. Health consequences of Relative Energy Deficiency in Sport (RED-S)



Note. From Br J Sports Med. (Mountjoy et al. 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://bjsm.bmj.com/content/48/7/491>). Permission pending.

Health Outcomes of LEA

Menstrual Dysfunction

Menstrual cycle disturbances in female athletes participating in arduous exercise and training is frequently observed, particularly within elite populations (Doyle-Lucas et al., 2010; Marcus et al., 1985). Development of menstrual dysfunction in response to exercise and insufficient dietary intake has been well researched in recent years, however, the long term effects of LEA on reproductive hormones and menstrual function is still unclear and debated (Loucks & Thuma, 2003; Slater, 2015).

A change in menstrual function is one of the major signs and symptoms of LEA in females, with disruptions in cycle presenting along a continuum of severity (De Souza & Williams, 2004). There are a number of menstrual function complications that develop due to LEA, which include but are not limited to amenorrhea, functional hypothalamic amenorrhoea (FHA), oligomenorrhea, luteal phase deficiency (LPD) and anovulation. FHA is defined as secondary amenorrhoea due to a gonadotropin-releasing hormone (GnRH) deficiency, triggered by excessive exercise or nutritional deficits (Caronia et al., 2011). Oligomenorrhea is known as having irregular menstrual cycles of >35 days in length. Subclinical issues such as LPD which is inadequate progesterone secretion (Andrews et al., 2015), and anovulation, known as having a regular cycle though not ovulatory and low progesterone present, are also within the realm of menstrual disturbances commonly observed within athletes (Loucks et al., 2011; Loucks & Thuma, 2003; Mallinson & De Souza, 2014; Slater, 2015). The most severe menstrual disturbance along the chain of cycle abnormalities is amenorrhea, which is a loss of menarche, and it is known to be induced by severe energy deficiencies (Mountjoy et al., 2018a; Reed et al., 2015; Williams et al., 2015). Moreover, amenorrhea can be further explained as primary

amenorrhea, which is an absence of initiation of menses by 14-16 years of age, and secondary amenorrhea, which can be defined as the absence of menses for 3 months or more in a previously normal menstruating female (Master-Hunter & Heiman, 2006).

Although complex, current research supports the association of LEA causing an inhibition of the hypothalamus-pituitary-ovarian axis leading to decreased oestrogen and progesterone levels, which are vital for promoting bone formation (Kroshus et al., 2018; Mountjoy et al., 2018a; Rickenlund et al., 2005; M. Warren & Fried, 2001). In addition, oestrogen increases the absorption of calcium into blood and accumulation into bone, which is facilitated by progesterone (Mountjoy et al., 2014). Oestrogen is also known to have an influence on muscle repair, regenerative processes and post exercise muscle damage (Tornberg Å et al., 2017), therefore, when oestrogen is deficient, muscle atrophy occurs and therefore contributes to muscle weakness, similar to that observed in menopausal women (Collins et al., 2019). Sipila and colleagues (2001) examined the administration of hormone replacement therapy (HRT, Oestradiol and Progestogen) in post-menopausal women ($n=80$). Four random groups were assigned: exercise, HRT, exercise+HRT (ExHRT) and control. Knee extension torque and vertical jump height were evaluated, alongside lean tissue cross sectional area (LCSA), as well as the relative proportion of fat within the muscle compartment being measured for the quadriceps and lower leg muscles. The ExHRT group displayed significant increases in knee extension torque (8.3%) and vertical jumping height (17.2%) when compared to the control group (-7.2%). The LCSA of the quadriceps significantly increased in the HRT (6.3%) and ExHRT (7.1%) groups when compared with the exercise and control group (2.2% and 0.7% respectively). The results provide merit to the aforementioned statements, as the authors concluded that muscle performance, muscle mass and muscle composition are

improved by HRT, and seems to have a larger beneficial effect when combined with high-impact physical training.

An early study by Castelo-Branco and colleagues (1996) investigated bone mass and menstrual cyclicity in females with hirsutism (excessive hair growth, $n=52$). Their most notable finding was that oligomenorrhoeic/amenorrhoeic females ($n=27$, 52%) displayed significantly lower bone mineral density (BMD) than eumenorrhoeic participants ($p<0.01$) (Castelo-Branco et al., 1996). BMD can be defined as the decrease in relative value of mineral per measured bone area (Snow-Harter & Marcus, 1991) or impaired bone health. Similar percentages of oligomenorrhoea and amenorrhoea were reported in a review by Gibbs and colleagues (2013), with exercise-associated menstrual disturbances (EAMD, oligomenorrhoea and amenorrhoea) being observed in up to 56% of exercising women. These numbers are concerning, as menstrual disturbances are known to negatively impact bone health and fertility, whilst increasing incidence of stress fractures (Gibbs et al., 2013). This is supported by Bennell and colleagues (1999) who concluded in their review that athletes with oligomenorrhoea or amenorrhoea are associated with a 2 to 4 fold greater incidence of stress fractures and low BMD (Bennell et al., 1999; Ducher et al., 2011). A further study by Rauh and colleagues (2010) also supports the history of menstrual disturbance being a risk factor for injury, investigating menstrual dysfunction and injury occurrence in high school athletes ($n=163$). Results showed that 25% ($n=41$) of participants were oligomenorrhoeic or amenorrhoeic. Interestingly, the athletes who reported menstrual dysfunction were almost 3 times more at risk of sustaining an injury than that of athletes who were eumenorrhoeic (Rauh et al., 2010).

As aforementioned, lowered progesterone levels can be detrimental to both menstrual

function and bone health in particular as progesterone is a facilitator in bone formation (Mountjoy et al., 2014; Prior et al., 1990). A prospective study by Prior and colleagues (1990) involving exercising premenopausal females ($n=66$) reported that those with ovulatory disturbances (recurrent short luteal phases and anovulatory cycles) ($n=13$) experienced a concerning bone mineral loss of approximately 4.2% per year (Prior et al., 1990).

The first cross-sectional study by Silva and colleagues (2018) completed in acrobatic gymnasts ($n=82$, 61 females & 21 males) discovered that 60% ($n=9$) of the 15 menstruated female participants were amenorrhoeic. The group displayed a presence of LEA, low body fat, reduced sleep, alongside inadequate energy intake relative to what their training demands require (Silva et al., 2018). Comparably, Civil and colleagues (2018) completed a cross-sectional study in elite ballet dancers ($n=20$), which found that 40% of participants displayed menstrual dysfunction (amenorrhea [$n=5$, 25%], oligomenorrhea [$n=3$, 15%]), with 65% of the total cohort being classified at risk of RED-S (Civil et al., 2018). As highlighted in the aforementioned studies, the female population experience a range of varied menstrual disturbances that subsequently have a negative impact on a range of health areas. Furthermore, the previous research shows that LEA consists of many multifaceted variables that interlink and therefore impact various physiological, psychological and performance factors.

Bone Health

A common implication many athletes face when experiencing LEA are the adverse effects of BMD reduction. As mentioned above, menstrual dysfunction and bone health variables interlink closely as subsequent impacts of LEA. Osteoporosis is a form of BMD reduction,

and is characterised as a disease with observed low bone mass and deterioration of bone tissue, which can result in compromised bone strength and cause an increased risk of fractures (Sözen et al., 2017). Osteoporosis can also be defined by a T score (retrieved through the gold standard BMD assessment dual x-ray absorptiometry [DXA]) of less than 2.5 or more below that of the mean level for a young adult reference population (Rachner et al., 2011; Sözen et al., 2017). Bone stress injuries (BSI) may be defined as a fatigue or exhaustion fracture due to repetitive stress on normal bone, or when normal stress is exerted on abnormal bone (low BMD) (Kiuru et al., 2004) Although BSI can result from overuse, it has been concluded that BSI and low BMD frequently occur due to menstrual dysfunction (amenorrhea, FHA, LPD), more specifically due to a reduction in oestrogen and progesterone (Ducher et al., 2011). Recent research has concluded that recovery from BSI can be further complicated by the presence of menstrual dysfunction and amenorrhea, as well as low BMD which are both risk factors within the FAT (Melin et al., 2019).

An early study by Marcus and colleagues (1985) investigated menstrual function and bone health in female distance runners ($n=17$). The results depicted that BSI occurred more frequently within women with amenorrhea compared to eumenorrheic women (Marcus et al., 1985). Another study completed in female distance runners ($n=127$) by Kelsey and colleagues (2007) discovered that athletes with current or past menstrual irregularities (amenorrhea) have a threefold greater risk of stress fractures compared to those with normal/eumenorrheic menses (Kelsey et al., 2007). Consistent with recent research, an earlier study in female track and field athletes ($n=53$) by Bennell and colleagues (1995) reported that athletes with a history of oligomenorrhea were six times more likely to have suffered a stress fracture in the past, with risk eight times more likely

in those who reported being careful about their weight (Bennell et al., 1995). Furthermore, a prospective study by Rauh and colleagues (2006) in female marine recruits ($n=824$) investigating the risk factors of overuse injuries, reported that participants experiencing secondary amenorrhea demonstrated almost a threefold increase of lower extremity stress fracture risk. A secondary finding was that once injured, the participant had a 2 to 3.5-fold increased risk of a subsequent stress fracture injury (Rauh et al., 2006). The previous research clearly displays the increased risk and incidence of stress fractures in females with current or previous menstrual irregularities, which further confirms the concept that bone health and menstrual function are two interrelated outcomes of LEA that have an effect on one another.

A recent study by Melin and colleagues (2015) in female endurance athletes ($n=40$) discovered that 67% displayed menstrual dysfunction, with 45% of the participants experiencing impaired bone health (osteoporosis in lumbar spine, $n=3$ & low BMD, $n=15$) (Melin et al., 2015). Furthermore, a study by Beals & Hill (2006) in mixed sport collegiate athletes ($n=112$) reported that 21% of participants displayed amenorrhoea, with nearly 19% of participants reporting a previous stress fracture (Beals & Hill, 2006). These findings are supported by Day and colleagues (2015) study also in collegiate athletes ($n=25$) who found that 40% of participants were amenorrhoeic, and 32% of participants reported having a history of one or more stress fractures (Day et al., 2015). Moreover, in a study by Barrack and colleagues (2014) in University athletes and recreational exercisers ($n=259$), it was observed that participants who had suffered a BSI displayed significantly lower percentages of body fat ($p<0.05$) and BMD in the femoral neck, total hip and lumbar spine ($p<0.05$, <0.05 and <0.05 respectively) compared with those who had not sustained a BSI previously (Barrack et al., 2014)

Impaired bone health is not always obvious and does not necessarily have clear symptoms, therefore commonly referred to as the silent component of LEA (Slater, 2015), with many athletes not discovering that they have low BMD or impaired bone health until they have already developed a stress fracture (Slater, 2015). Bone health can be driven by many factors including poor energy status and compromised menstrual function, often being considered the most detrimental and irreversible triad component (Petkus et al., 2017), which has been highlighted in the aforementioned studies. As aforementioned, low BMD is closely associated with insufficient production of oestrogen and progesterone which is often due to menstrual dysfunction, a common causality of LEA. Risk factors of bone health and menstrual function are closely interlinked and often difficult to differentiate, causing difficulty in the assessment of LEA and the correlated symptoms (Ducher et al., 2011).

Injuries

It is well documented in the previous section, that low BMD and prevalence of stress fractures are associated with athletes in a state of LEA. It is common for athletes to experience injuries due to the training load experienced and the nature of certain sports, however, studies investigating soft tissue injuries in relation to LEA are currently lacking.

Rauh and colleagues (2010) reported that 37.4% of high school athletes ($n=163$) had at least one musculoskeletal injury severe enough to result in an absence from training and competition. Although a majority of injuries were chronic or overuse in nature, they did not report specific injury types (e.g. sprain, tendinitis, stress fracture), therefore making it difficult to know how many of these injuries were soft tissue (Rauh et al., 2010). Rauh and colleagues (2010) did not report training loads, exercise programmes or diet logs in

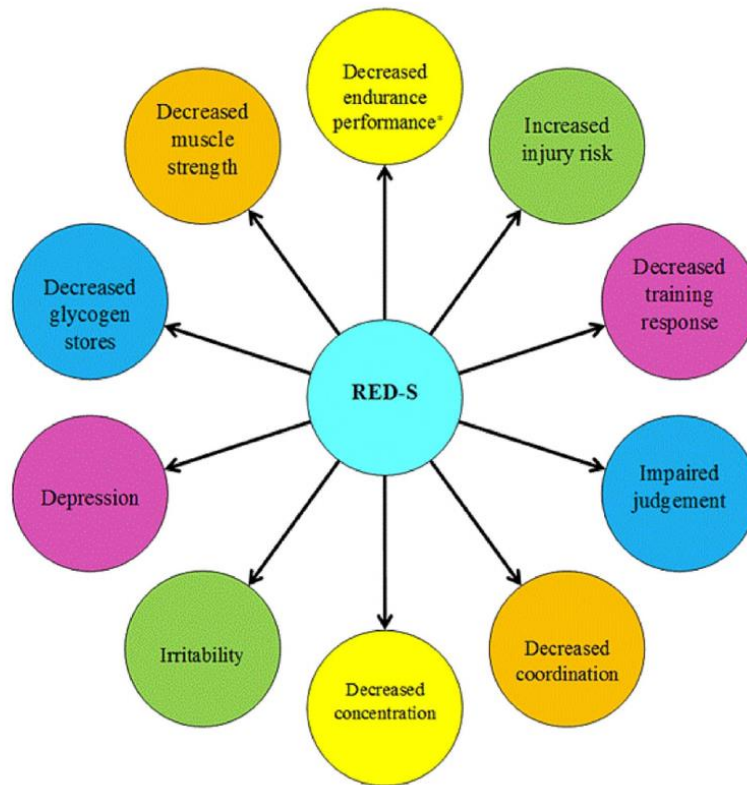
this study, thus difficult to conclude whether these injuries were specific to LEA or perhaps due to excessive exercise, poor programming or restricted eating, which are all risk factors related to LEA. Slater (2015) reported a significant association between the number of exercise related injuries suffered in the past year and risk of LEA. It was reported that females were 2.04 times more likely to be at risk of LEA for every extra injury they had sustained within the last 12 months. (Slater, 2015). According to Benson et al. (1996), amenorrhea has been related to scoliosis, and an increased risk of soft tissue injury, however, this is yet to be conclusively reported in the previous research. A potential reason may be due to the lack of definitions and terms of injury. Logue and colleagues (2018) acknowledge that a standardised definition of injury is required, to allow accurate representations of injuries in future studies, which will permit researchers to investigate if there are associations between LEA and other types of injury excluding stress fractures (Logue et al., 2018).

Performance Impairment

The performance effects due to LEA have not yet been well investigated, however some researchers have concluded over the recent decades that low EA is associated with decreased performance variables and effects in athletes such as swim performance (Vanheest et al., 2014), impaired judgement, increased injury risk, and decreased coordination (Ackerman et al., 2019), reaction times (Tornberg Å et al., 2017), VO_{2max} (Ingjer & Sundgot - Borgen, 1991) and impaired recovery (Mountjoy et al., 2018b). Furthermore, Mountjoy and colleagues (2014) have displayed the ten potential performance effects resulting from LEA in athletes (Figure 3). The RED-s model displays an extensive range of physical, neuromuscular, cognitive and performance factors that can be impacted by LEA or RED-S as a condition.

A recent study by Ackerman and co-authors (2019) examined the association of LEA and eight of the ten RED-S performance effects (Figure 3) via an online questionnaire in 1000 female athletes. It was identified that compared to those with adequate EA, LEA athletes were over 4 times more likely to report impaired judgement ($p < 0.0005$) and 2.1 times more likely to report a decreased training response ($p < 0.0005$). In addition, the authors concluded that LEA is associated with a negative influence on decreased coordination (Odds Ratio [OR] 1.58, $p = 0.007$), decreased concentration (OR 2.01, $p = 0.001$) and decreased endurance (OR 1.47, $p = 0.015$), as well as a 38.5% increased injury risk (Ackerman et al., 2019). Similarly, Tornberg and associates (2017) completed a study in elite endurance athletes ($n = 30$) investigating neuromuscular performance in amenorrhoeic athletes compared to eumenorrhoeic athletes. Results show those athletes who were eumenorrhoeic displayed a significantly faster reaction time (RT) than those who were amenorrhoeic ($p = 0.025$). Reduced reaction time was associated with lower blood glucose, T_3 , oestrogen and higher cortisol levels, which as aforementioned, are all alterations frequently observed in athletes with amenorrhea (Tornberg Å et al., 2017).

Figure 3. Potential performance effects of RED-S



From Br J Sports Med. (Mountjoy et al. 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://bjsm.bmj>). Pending Permission.

An energy deficit is known to negatively influence an athletes performance, with maximal oxygen performance (VO_{2max}) previously shown to decrease significantly (28%) in female athletes during a state of starvation or malnutrition, whilst running speed significantly decreased in addition (Ingjer & Sundgot - Borgen, 1991). Logue and colleagues (2018) hypothesise that continued dietary restriction for periods of time would detrimentally affect sports performance through the depletion of glycogen stores (Logue et al., 2018). This hypothesis is supported by El Ghoch and colleagues (2013) who state that the current research indicates restricted diets have a negative effect on fitness and sport performance by causing LEA, loss of fat and lean mass and dehydration (El Ghoch et al., 2013).

The relationship between menstrual dysfunction and impaired performance is supported by Vanheest and co-authors (2014), who studied the effects of ovarian suppression (LPD) on swimming performance in national calibre teenage females ($n=10$). It was reported that there was a 9.8% decline in swim velocity in swimmers with ovarian suppression (defined as serum P₄ concentrations during the luteal phase of less than 5 ng·mL⁻¹) (Vanheest et al., 2014), in comparison to an 8.2% increase in performance in the eumenorrheic swimmers. It was reported that the cyclic (CYC, defined as serum P₄ concentrations during the luteal phase of at least 5 ng·mL⁻¹ or greater at week 0 or week 2) (Vanheest et al., 2014) group had significantly greater EI than the OVS group throughout the study ($p \leq 0.001$). The significant difference between dietary intake between groups over the course of the study makes it difficult to conclude that the reduction in swimming performance was solely due to menstrual disturbances, or perhaps due to the low caloric intake compared to that of the CYC group. The study by Vanheest and colleagues (2014) was the first to demonstrate the harmful effects that LPD has on sport performance, as previously mentioned is a menstrual disturbance commonly associated with LEA (Andrews et al., 2015). Furthermore, Mooses & Hackney (2017) suggest in a review on African runners that although low BMI is beneficial for running performance, maintaining a low body weight through long-term LEA will likely lead to negative adverse effects on performance and overall health through lowered luteinizing hormone, T₃ and leptin (Melin et al., 2019; Mooses & Hackney, 2017). Both short and long term LEA is recognised to negatively impact sports performance through many indirect mechanisms, including the reduction of recovery and impairment of optimal muscle mass and function (Mountjoy et al., 2018a; Nattiv et al., 2007). A supporting study in a male combat sport athlete by Langan-Evans and colleagues (2020) reported that 7 weeks of low EA (average of 20kcal/kgFFM/day) permitted a reduction in body mass

(9.8kg, <13.5%) and fat mass associated with RED-S symptoms. In contrast, a period of five consecutive days of EA < 10kcal/kgFFM/day induced disruptions to the hypothalamic pituitary gonadal axis, and RMR, both common responses to periods of excessive LEA (Langan-Evans et al., 2020). Furthermore, a very recent review by Logue and co-writers (2020) state that the effects of LEA, including low levels of oestrogen and menstrual dysfunction is associated with a higher incidence of injuries as well as delayed recovery, therefore having an impact on overall performance (Logue et al., 2020).

Although not yet well documented, the aforementioned literature focusing on negative performance effects as a result of LEA provide an overview of various ways athletic performance can be harmed by menstrual dysfunction or bone health as a result of LEA. The associated performance impacts of LEA require further research to support Ackerman and colleagues (2019) study investigating the specific potential performance impacts influenced by LEA highlighted in the RED-S model (Figure 3).

In contrast to the previous physiological and performance outcomes of LEA, it is though that LEA can also negatively impact psychological health or LEA may develop due to psychological behaviours. As LEA is widely associated with many physiological and performance effects, it would be expected that athletes would experience psychological impairments in addition (Schofield et al., 2019).

Although very limited research has been done in this area, the previously mentioned study by Ackerman and associates (2019) that investigated the RED-S model and the potential performance outcomes associated, did include some psychological measures. It was reported that athletes with LEA were nearly 2.5 times more likely to report feelings of

depression and nearly 2 times more likely to report irritability compared to those with sufficient EA (Ackerman et al., 2019). It is important to note that the psychological relationship in the RED-S model is bi-directional, as psychological consequences can either precede RED-S or be the direct result of RED-S. E.g. Stress and/or depression can result in low EA and restrictive eating/disordered eating can also be a result of low EA (Mountjoy et al., 2014). Given the detrimental impact that LEA symptoms may have on psychological health and vice versa, it is essential that future research investigates this area further.

Prevalence of Low Energy Availability

It is evident LEA occurs across a wide range of sports and training levels however, there is a large variance in LEA prevalence. Previous research has shown a prevalence of LEA in 2.2% of non-athletes (Muia et al., 2016), 44% in recreational athletes (Slater, 2015), 90% in endurance cyclists during mid-season competition (Viner et al., 2015) and as high as 100% in 'high-risk' sports such as synchronised swimming (Schaal et al., 2017), ballet dancing (Łagowska & Kapczuk, 2016) and jockey racing (Dolan et al., 2011). The large variance of LEA prevalence in published results may be due to athlete recruitment in sport specific populations, and the range of methods, indicators or predictors used to assess LEA (Black et al., 2020). Sub-optimal energy is often reported in athletes participating in 'higher risk' sports where low bodyweight, low-fat mass and leanness is desirable or has a performance advantage (Heaney et al., 2008). Specificity

Prevalence of LEA within individual sports

In regard to individual sporting codes, Hoch and colleagues (2011) completed a study in professional female ballet dancers ($n=22$). The prevalence of LEA was estimated by

incorporating dietary records and accelerometers to identify energy intake and energy expenditure. It was reported that 77% of the ballet dancers displayed a negative energy balance, resulting in a state of LEA (Hoch et al., 2011). Similarly, Doyle-Lucas and colleagues (2010) also investigated the prevalence of LEA in professional ballet dancers ($n=30$), however dietary records and activity logs were implemented to assess EA, with 100% of ballet dancers displaying $<30\text{kcal/kgFFM/day}$ (Doyle-Lucas et al., 2010).

A recent study by Schaal and colleagues (2017) in female synchronised swimmers ($n=11$) investigated EA and EI during a phase of intensified training. At baseline, all swimmers' EA was already significantly lower than 30kcal/kgFFM/day , a threshold which is frequently used to define LEA. There was a further 28% decrease in EA from baseline to the end of the four week training phase ($18.0\text{ kcal/kg/FFM/day}$) (Schaal et al., 2017). In a similar cohort, Vanheest and co-authors (2014) completed a study in junior elite female swimmers ($n=10$). It was found that 100% of athletes that were classified as ovarian suppressed displayed a negative energy balance of 200kcal/day or more, which the authors used to assess low energy availability (Vanheest et al., 2014).

Endurance and distance runners have also been well documented, though prevalence of LEA within this population is varied. Melin and colleagues (2016) investigated LEA in 25 female endurance athletes, with only three athletes displaying LEA ($<30\text{kcal/kgFFM/day}$), although 11 (44%) participants presented reduced EA ($<45\text{kcal/kgFFM/day}$) (Melin et al., 2016). An earlier study also by Melin and colleagues (2014) in endurance athletes ($n=40$) displayed similar results, with 20% of athletes observed with an EA of 30kcal/kgFFM/day or less, and 42.5% of participants displaying subclinical LEA ($<45\text{kcal/kgFFM/day}$) (Melin et al., 2015). Muia and colleagues (2016)

reported similar LEA prevalence in female distance runners ($n=61$), with 17.9% of participants exhibiting LEA (30kcal/kgFFM/day). Interestingly, 75.4% of participants were classified with subclinical or reduced LEA (<45kcal/kgFFM/day), indicating that less than 7% of the athletes exhibited adequate EA levels (>45kcal/kgFFM/day) (Muia et al., 2016). A further study in female distance athletes ($n=35$) reporting slightly higher prevalence of LEA than the previous studies was completed by Heikura and colleagues (2018). It was reported that 31% of participants exhibited an EA of 30kcal/kgFFM/day or less (Heikura et al., 2018). The prevalence of LEA in endurance and distance runners is concerning, and although rates are not as high as reported in other individual sports, the detrimental health outcomes of LEA have warranted this population being heavily investigated in the past.

Another individual sporting code that has had some previous investigation on the prevalence of LEA, is female track and field athletes. Day and colleagues (2015) reported 52% of elite track and field athletes ($n=25$, including runners, sprinters, hurdlers and jumpers) displayed EA of 30kcal/kgFFM/day or less (Day et al., 2015). Similarly, a recent study by Sygo and associates (2018) investigated LEA in female sprinters ($n=13$). Through measurements of the LEAF-Q, RMR and BMD results, it was reported that 31% of athletes presented at least one indicator of LEA preseason, with an increase to 54% post-season (Sygo et al., 2018).

Table 1. Prevalence of LEA within individual sport athletes

Study	Sex	Sample Size (n)	Athlete Population	Measure of LEA	Subjects with LEA (%)
Schaal et al., 2017	F	11	Synchronised swimmers	EA < 30kcal/kg FFM/day	Baseline: 100 I-T Week 2: 100 I-T Week 4: 100
Hoch et al., 2011	F	22	Ballet dancers	Negative energy balance (caloric intake – EEE)	77
Doyle-Lucas et al., 2010	F	30 (15 dancers; 15 sedentary control)	Ballet dancers	RMR	100
Melin et al., 2016	F	25	Endurance athletes	EA < 30kcal/kg FFM/day	12
Muia et al., 2016	F	61	Distance runners	EA < 30kcal/kg FFM/day	17.9
Melin et al., 2014	F	40	Endurance athletes	EA < 30kcal/kg FFM/day	20
Vanheest et al., 2014	F	10 5 cyclic 5 ovarian suppressed	Swimmers	Negative EB > 200kcal/day [#]	OVS: 100
Day et al., 2015	F	25	Track & field athletes	EA < 30kcal/kg FFM/day	52
Silva and Paiva, 2015	F	67	Rhythmic gymnasts	EA < 30kcal/kg FFM/day	44.8
Dolan et al., 2011	M	27	Jockeys	EA < 30kcal/kg FFM/day	Competitive race days: 100
Heikura et al., 2018	F/M	Female: 35	Distance athletes	EA < 30kcal/kg FFM/day	31
Sygo et al., 2018	F	13	Sprinters	LEAF-Q, RMR, BMD	PRE: 31% [^] POST: 54% [^]
Folscher et al., 2015	F	306	Ultra-marathon runners	LEAF-Q	44.1

Abbreviation's: I-T, Intensive training; SC-EA, sub-clinical energy availability (30-45kcal/kgFFM/day); OVS, ovarian-suppressed; EEE, exercise energy expenditure; EB, energy balance

Notes: [#]Negative EB values > 200kcal/day were considered to be an energy deficit due to possible variability in measuring energy intake and total daily energy expenditure.

[^]PRE & POST season values present as number of participants who display with at least one primary & one secondary indicator of LEA.

Prevalence of LEA within team sports

The known prevalence in elite team sports is limited in comparison to the individual sport population, and to the authors knowledge, the current research in elite team sports has only been investigated in Football and Rugby Union athletes (Table 2) (Braun et al., 2018; Christensen, 2019; Dobrowolski & Wlodarek, 2020; Groom, 2019; Kumar, 2019; Reed et al., 2013).

Reed and colleagues (2013) completed one of the first studies investigating the prevalence of LEA in an elite team sport (football) cohort ($n=19$) across a season. It was reported that 26% of athletes exhibited LEA pre-season, with an increase to 33% mid-season, and an off season prevalence of 12% via the threshold of EA < 30kcal/kgFFM/day (Reed et al., 2013). A higher prevalence of LEA was observed in a recent study with elite football athletes ($n=56$) by Braun and colleagues (2018). It was reported that 53% of participants displayed LEA (30kcal/kgFFM/day), displaying a much higher prevalence than observed by Reed and colleagues (2013) (Braun et al., 2018). Furthermore, the most recent study in 30 elite footballers by Dobrowolski and colleagues (2020) discovered the highest prevalence observed within this population with authors reporting a concerning prevalence of 64.1% of athletes displaying an EA of 30kcal/kgFFM/day or less (Dobrowolski & Wlodarek, 2020). Although the aforementioned studies in team sports have all used the same assessment of EA (30kcal/kgFFM/day), the differences in prevalence observed may be due to differences in training volumes or programmes, dietary influences and perhaps an objective classification of the term 'elite' athletes, as this may be classified differently between researchers.

Table 2. Prevalence of LEA within elite team sport athletes

Study	Sex	Sample Size (<i>n</i>)	Athletes	Measure of LEA	Subjects with LEA (%)
Reed et al., 2013	F	19	NCAA Division 1 Soccer players	EA < 30kcal/kg FFM/day	Preseason: 26 Midseason: 33 Offseason: 12
Dobrowolski et al., 2020	F	31	Professional soccer players	EA < 30kcal/kg FFM/day	64.1
Braun et al., 2018	F	56	Elite soccer players	EA < 30kcal/kg FFM/day	53
Groom, 2019	F	24	Elite Rugby 7's players	LEAF-Q	50
Christensen, 2019	F	20	Elite Rugby 7's players	LEAF-Q RMR	LEAF-Q: 55 RMR: 58
Kumar, 2019	F	23	Elite Rugby 7's players	LEAF-Q	52.2

The prevalence of LEA in female rugby 7's athletes have also been investigated, with results being very comparable to the football population. In a cohort of 24 elite rugby 7's athletes, Groom (2019) discovered that 50% of the population were 'at-risk' of LEA based on their answers to the LEAF-Q (Groom, 2019). Similarly, Kumar (2019) reported a comparable prevalence of LEA in 23 elite rugby 7's athletes through the implementation of the LEAF-Q. Kumar (2019) reported a slightly higher prevalence than Groom (2019), with 52.2% of participants classified as 'at-risk' of LEA (Kumar, 2019). Furthermore, Christensen (2019) reported the highest prevalence of LEA in elite rugby 7's athletes, with 55% of athletes classified as 'at-risk' of LEA by the LEAF-Q. However, a slightly

higher prevalence of 58% was observed when measuring LEA by RMR values (Christensen, 2019).

The findings from the recent research of LEA in the team sport population suggest that despite the common misconception that team sports potentially have lower work rates and intensity compared to individual sport populations, the prevalence of LEA is very similar to what has been previously observed in individual sport athletes. A team sport yet to investigate the prevalence of LEA is netball, which is a team sport intermittent in nature, with frequent changes of movement and many short and sharp direction changes and sprints (Davidson & Trewartha, 2008). Previous research has shown that elite netballers spend the majority of the one hour game at over 85% of their maximum heart rate (MHR) (Kennedy et al., 2011). In a time motion analysis study completed in professional netball athletes, Davidson and colleagues (2007) reported that the Centre position changed activity every 2.8 seconds and spent 52.2% of the one hour game either jogging, shuffling or running, with a total of 8km travelled over the period of the game, which is much further than reported in rugby union players (4.9km) (Davidson & Trewartha, 2008; Deutsch et al., 2007).

Furthermore, Renard and colleagues (2021) have recently discovered that female team sport athletes commonly present diets that are inadequate in overall energy, carbohydrate and iron intake. The authors suggested that female team sport athletes could be viewed as a 'high-risk' population for developing LEA due to frequent insufficient dietary intakes combined with the high energy demands required in training and competition. (Renard et al., 2021). It has been highlighted in research (Kroshus et al., 2018; Warrick et al., 2020) that team culture and coach influence has an impact on health consequences linked to LEA, such as coaches criticism being closely associated with athletes' disordered eating,

social physique anxiety, and feelings of guilt and shame (Coppola et al., 2014). Moreover, Sabiston and colleagues (2020) state the detrimental impact that self-comparison or coach/teammate lead comparisons between athletes in team sport environments can have on dietary intake, body image concerns and therefore the psychological effect this can cause (Sabiston et al., 2020).

Screening of LEA

The screening and assessment of LEA is challenging, as the signs and symptoms that correlate with energy deficiency are often subtle or are difficult to quantify and measure. Although a range of screening tools exist, at present there is no 'gold standard' EA assessment with a lack of overall consensus on which tool has the best efficacy. Therefore, at present diagnosis of LEA is commonly achieved through a combination of measures, as opposed to one single measure. Because the components of LEA are difficult to assess in the absence of experts (Doctor, Nutritionist, Physiologist, Psychologist) it is difficult to find methods that are both practical for an individual and reliable.

Clinical Assessment

Resting metabolic rate (RMR) is the minimum energy required to undergo the bodies basic physiological functions, and is primarily dependant on lean mass (Schofield et al., 2019). RMR values are often used as a tool to estimate EA, and effectively determine the presence of LEA, therefore, the accuracy and reliability of assessment is vital (Schofield et al., 2019). Schofield and colleagues (2019) state that accessibility, cost and equipment requirements are often barriers when using RMR as a measure of LEA, and predictive RMR equations such as the Harris-Benedict and Cunningham equations were developed to reduce complexity. However, Schofield and colleagues (2019) conclude that current

predictive equations do not account for FFM in athletes, therefore underestimating true RMR and hence exercise energy expenditure. Logue and co-authors (2020) offer support to this in a recent review, stating that the use of predictive equations such as the Harris-Benedict and Cunningham equations displayed large variability in both male and female ballet dancers, ranging from 35% to 100% of female athletes “at-risk” of LEA dependant on the predictive equation used. Therefore, the prevalence of athletes identified as ‘at-risk’ of LEA will vary dependant on the predictive equation used and whether FFM is accounted for (Logue et al., 2020).

Various methods of RMR assessment were tested for reliability in sub-elite female athletes ($n=25$) (Mackay et al., 2019). The Parvo Medics TrueOne analyser was compared to three predictive RMR equations (Harris-Benedict, Mifflin-St Jeor, World Health Organisation). The results found that the Parvo Medics TrueOne analyser produced *almost perfect* levels of test-retest reliability (0.92, intra-class correlation coefficients [ICC]). However, the three predictive equations underestimated RMR by 131-139kcal/day, and when compared to the Parvo analyser, the results were questionable, with low levels of agreement. Mackay and colleagues (2019) concluded that the Parvo Medics TrueOne analyser is a reliable tool for measuring RMR, while caution was suggested when using predictive equations in female athletes due to the underestimation of RMR. Thus, the development of a reliable and practical protocol to assess RMR in athletes is required, due to the inaccessibility and impracticality of laboratory RMR tests, and the unreliability of the current predictive RMR equations (Logue et al., 2020).

Blood sample analysis is a clinical assessment to aid in the determination and diagnosis of LEA in athletes. Insulin, oestradiol, T₃, thyroid-stimulating hormone, leptin,

luteinizing hormone (LH), progesterone and cortisol are all markers typically assayed in blood sample analysis to detect LEA (Black et al., 2018; Heikura et al., 2018). Loucks and colleagues (2003) analysed the incremental effects of restricted EA on metabolic substrates and hormones through blood analysis. The authors identified detrimental effects to several markers, including the substantial decline in insulin as EA reduces, and an increase in cortisol which progressively increases as EA decreases. T_3 was significantly inhibited by an EA of 30kcal/kgFFM/day ($p < 0.05$) and was further suppressed by a reduction in EA of 20kcal/kgFFM/day ($p < 0.01$). In addition, Leptin was suppressed by an EA of 30kcal/kgFFM/day ($p < 0.01$), however, further decreases in EA of 20 and 10 kcal/kgFFM/day did not produce significant changes in leptin levels (Loucks & Thuma, 2003). Heikura and colleagues (2018) state that the combination of qualitative screening tools (LEAF-Q, RED-S) and quantitative measures of reproductive function (blood reproductive and metabolic hormones, and RMR) may provide a more reliable representation of an individual's EA, thus, provide a more sensitive way to diagnose LEA. The authors concluded that the assessment of physiological symptoms of low EA (hormone concentrations and menstrual function) provides a better insight of the overall health status of an individual, rather than providing a diagnosis based on current EA measured through energy expenditure and dietary intake (Heikura et al., 2018).

Subjective Assessment

Validated questionnaires such as the Low Energy Availability in Females Questionnaire (LEAF-Q) are utilised in populations where invasive procedures such as frequent blood tests, hormonal profiling and RMR testing is not always applicable. The LEAF-Q is designed as an assessment tool to identify females risk classification for LEA, most commonly used in large elite athlete cohorts. The easily administered questionnaire

produced high levels of sensitivity (78%) and specificity (90%) to identify injury history, gastrointestinal function, and menstrual function. Through an early identification/prevention lens, the LEAF-Q can be effective to detect signs and symptoms in individuals to promote early intervention or treatment. A total score of ≥ 8 is indicative for an 'at-risk' classification, whereas a score of 7 or less is classed as 'not at-risk' of developing LEA (Groom, 2019). At present, there is no male specific screening tool to identify LEA in male populations (Logue et al., 2018).

A very recent review by Sim & Burns (2021) highlight the questionnaires currently available as measures for LEA and RED-S in athletes (Sim & Burns, 2021). Besides the most commonly used questionnaire, the LEAF-Q, there are other screening tools such as the RED-S Clinical Assessment Tool (RED-S CAT), the eating disorder inventory (EDI), and the Female Athlete Triad Screening Questionnaire which are all subjective screening tools to identify risk factors, behaviours or symptoms of LEA, RED-S or the FAT. The RED-S CAT is a preferred tool for professional use and employs a 'red light – yellow light – green light' risk assessment focussing more on behaviours associated with LEA rather than signs and symptoms that the LEAF-Q assesses. The RED-S CAT can be used within male and female cohorts, though further validation is needed as it is agreed that LEA & RED-S affects an extensive range of body systems involving but not limited to low body fat, menstrual irregularities, recurrent illness and injury, and behavioural characteristics, therefore challenging to contribute an accurate screening diagnosis (Sim & Burns, 2021).

Dietary and exercise logs are common, simple and practical measures of energy intake and expended energy, however these methods are generally inaccurate and are typically

only useful as a rough estimate in combination with other measurements such as questionnaires or RMR (Mountjoy et al., 2018a; Warrick et al., 2020). In addition, the demand of diet and training records are likely to cause participant burden, with diet records having a tendency to be more misreported than physical activity logs (Lane et al., 2019). Lane and colleagues (2019) implemented three-day diet and exercise records, in addition to completion of a questionnaire which collected exercise training behaviours, nutritional practices and physical characteristics. Instructions and guidance for measurement of diet and exercise were provided, however the authors reported the implementation of the subjective records as a limitation of their study which may have compromised validity, despite the additional direction of the records to limit in misreported information (Lane et al., 2019). Similarly, in a cohort of female footballers, Reed and associates (2013) assessed energy intake through a prospective three-day log, and exercise expenditure through the use of training logs in combination with heart rate monitor use. Comparable to Lane and colleagues (2019), Reed and colleagues (2013) provided participants with a completed diet record for reference, and tools to measure portions of food and drink as an attempt to limit the rate of misreported dietary intake. Reed and colleagues (2013) also highlighted the limitation of three-day diet logs as a measure of energy intake. Self-reported food records have been associated with underreporting, therefore, despite efforts to limit inaccuracies seen in previous literature, this may still be considered as a limitation (Reed et al., 2013). At present, to the authors knowledge there is no one gold standard assessment of LEA therefore it is recommended where possible, that a combination of subjective and objective measures is used.

Coach and Physician Awareness of LEA

As shown throughout the literature review, LEA is prevalent within a range of different

sports and level of athletes, reflecting the necessity for coaches, sports practitioners, support staff and physicians who work with athletes needing to be aware and knowledgeable of LEA. More specifically, it is important that people working with athletes are able to identify the possible signs and symptoms of LEA, whilst understanding the impact of LEA on performance, and most importantly athlete health. However, despite the increase awareness of LEA and RED-S in the athletic world, it has been reported that coaches lack basic understanding of LEA and the serious influences this has on female athlete health (Hamer et al., 2021).

Coaches play an essential role in the early detection and intervention in athletes presenting with signs of LEA, as they are often in a position where they are able to observe changes in an athlete's health and/or performance (Hamer et al., 2021; Kroshus et al., 2018). Mukherjee and colleagues (2016) investigated coaches' ($n=106$) awareness of the FAT and LEA. It was reported that a concerning 85% of the coaches responded that they had never heard of or were 'unsure' if they had heard about the Triad. Additionally, 89% of the coaches were not able to identify the components of the FAT (Mukherjee et al., 2016). Similarly, in a study completed among 931 qualified multispecialty physicians, only 37% of them were aware of the Triad, with 51% stating they would be comfortable treating or referring a patient with LEA (Curry et al., 2015). It is difficult to draw definitive conclusions on these results, as it is not clear whether the 51% of physicians being comfortable treating LEA is from the entire cohort or from the 37% of the physicians that were aware of the Triad. A study completed in high school level athletes ($n=240$) and their coaches ($n=10$) was completed by Brown and colleagues (2014). The findings showed that only three coaches had heard of the Triad, but only one could correctly identify all three components. Concerningly, three coaches thought that menstrual

irregularity due to sports performance was normal (Brown et al., 2014). These findings support the aforementioned study and highlight the importance of awareness and knowledge of LEA being required in coaches. Contrary to the findings by Mukherjee and colleagues (2016), a study by Troy and co-authors (2006) in multi-speciality practitioners ($n=163$) including sports medicine, rehabilitation, physical medicine, and general health professionals found that 66% of participants ($n=124$) had heard of the FAT, as well as 29% having heard of RED-S ($n=47$). It would be expected that health practitioners be aware of concepts such as the FAT and RED-S, though increased awareness within coaches specifically is required, as they are less likely to have encountered signs and symptoms of LEA compared to a qualified health professional.

Awareness of LEA, RED-S and the FAT is necessary within coaches, clinicians and trainers in all sports and disciplines. By enhancing awareness and understanding of LEA, it is likely to increase rates of early intervention and diagnosis, which would consequently decrease the prevalence of athletes in a state of LEA experiencing deleterious, long-term impacts of the condition (Warrick et al., 2020).

Summary

The current review shows that LEA is a complex health condition which impacts both female and male populations and is of great concern given the range of known health implications it imposes. The current review of the research acknowledges that LEA has an undesired influence on many areas of health and is not limited to variables such as menstrual function, bone health and athletic performance. The review also highlighted the need to raise the awareness of LEA and knowledge of the associated consequences amongst coaches, medical physicians and sports practitioners working within athletic

populations, as early detection and intervention is imperative to ensure a diagnosis before health and performance factors are severely compromised.

As highlighted in the current review, the prevalence of LEA varies from one population to another, with team sport athletes presently underrepresented in the current literature. Given the fact that team sport populations training demands are closely matched to those experienced by individual sport athletes, a greater understanding of the prevalence of LEA in a range of team sport populations, such as netball is needed.

**Chapter Two – Screening for risk of Low Energy Availability
in elite female netball athletes and the prevalence of injury**

Abstract

Introduction: An energy deficit occurs when the demands of exercise is not accounted for through caloric intake, often resulting in downregulation of normal physiological functions in an attempt to conserve energy as a means to survive. This indicates that the body is in a state of low energy availability (LEA). The aim of the current study is to investigate the prevalence of those classified ‘at-risk’ of LEA in elite female netball athletes using the Low Energy Availability in Females Questionnaire (LEAF-Q).

Methods: In a cross-sectional study, 53 elite female netballers (aged 24 ± 3.9 years) completed an adapted online version of the LEAF-Q, with four, non-validated sport-specific injury questions included.

Results: A total of 52.8% ($n=28$) of participants were classified as being ‘at-risk’ of LEA according to the LEAF-Q scoring system. Furthermore, 85.71% ($n=23$) of ‘at-risk’ participants reported having an injury within the past 12 months, with risk of LEA being 4.7 times more likely to occur among participants who experienced an injury within the recent year compared to those who reported no injury (OR = 4.7, 95% CI = 1.26-17.67, $p = 0.21$). In addition, 86.2% of all injuries sustained in the ‘at-risk’ group were classified as soft tissue in nature.

Discussion: LEA has the ability to severely impact health and athletic performance if left untreated or undiagnosed and is frequently reported amongst endurance sport athletes. The current study indicates that there is a large prevalence of LEA in elite netballers, which is a population to the authors’ knowledge that has not previously been studied. The prevalence of elite female netball athletes ‘at-risk’ of LEA is concerning, therefore prevention strategies and detection tools should be implemented and used more frequently to identify risk before health or performance is impacted. Furthermore, the team sport population has largely been underrepresented in LEA literature and warrant

further research of LEA.

Introduction

Elite athletes require sufficient nutrition to meet the extraordinary physiological demands experienced through vigorous training (Magee et al., 2020). Maintaining an energy balance, which is when energy intake equals energy expenditure, is crucial for optimal sporting performance and enhancing overall health (Loucks et al., 2011). Insufficient dietary intake relative to energy expenditure, resulting in an energy deficit, can cause athletes to be susceptible to low energy availability (LEA). LEA is whereby energy availability is too low for normal physiological functions to occur, producing negative adaptations where bodily functions downregulate to conserve energy. LEA poses a significant health risk and is associated with various unfavourable health and performance outcomes relative to areas such as thermoregulation, bone health, menstrual function and growth (De Souza et al., 2014; Logue et al., 2018; Mountjoy et al., 2014; Slater et al., 2016). Although not limited to females, female athletes are particularly predisposed to developing LEA, with previous research stating female athletes are 5.4 times more likely to be 'at-risk' of LEA compared to male athletes (Groom, 2019; Loucks & Thuma, 2003; Slater, 2015). Therefore, without early detection and/or intervention of LEA, female athletes' experiencing LEA risk significant long-term health effects including but not limited to; infertility, suppressed immune function, stress fractures and osteoporosis (Hamer et al., 2021; Mountjoy et al., 2018a).

It is evident LEA occurs across a wide range of sports and training levels however, there is a large variance in LEA prevalence. Previous research has shown a prevalence of LEA in 2.2% of non-athletes (Muia et al., 2016), 44% in recreational athletes (Slater, 2015), 90% in endurance cyclists during mid-season competition (Viner et al., 2015) and as high as 100% in high-risk sports such as synchronised swimming (Schaal et al., 2017), ballet

dancing (Łagowska & Kapczuk, 2016) and jockey racing (Dolan et al., 2011). The prevalence of LEA reported in the current literature within varied sports fluctuates greatly, with different populations being studied and different methods of indicators or predictors used, which may explain the large variance in published results (Black et al., 2020). Sub-optimal energy is often reported in athletes participating in “higher risk” sports where low bodyweight, low-fat mass and leanness is desirable or has a performance advantage (Heaney et al., 2008).

A large majority of previously published LEA research has focused on individual athletes such as swimmers (Schaal et al., 2017; Vanheest et al., 2014), endurance athletes (Heikura et al., 2018; Melin et al., 2014; Melin et al., 2015; Muia et al., 2016), track and field athletes (Day et al., 2015; Sygo et al., 2018), jockeys (Dolan et al., 2011; Wilson et al., 2018), and ballet dancers and gymnasts (Doyle-Lucas et al., 2010; Hoch et al., 2011; Łagowska & Kapczuk, 2016; Silva & Paiva, 2015). On the contrary, LEA has been largely overlooked in team sports, and more specifically in elite-level team sport athletes. To the authors knowledge, the current research in elite team sports has only been investigated in Football and Rugby Union athletes (Braun et al., 2018; Christensen, 2019; Dobrowolski & Wlodarek, 2020; Groom, 2019; Kumar, 2019; Reed et al., 2013). In a group of elite female football athletes ($n=56$), Braun and colleagues (2018) reported that 53% of participants had LEA. Similarly, Christensen (2019) discovered that 55% of elite female rugby 7's athletes ($n=20$) were ‘at-risk’ of LEA.

While there has been a recent increase in LEA research in elite team sport athletes, with results indicating a similar prevalence of LEA as found in individual sport athletes, a number of different team sports are yet to be represented in the research. To our

knowledge, the prevalence of LEA in elite female netball athletes has not yet been determined. Therefore, the present study aimed to identify the prevalence of LEA in New Zealand elite netball athletes using the validated Low Energy Availability in Females Questionnaire (LEAF-Q). A secondary aim of the study was to determine whether LEA had any significant association with injury rates in this cohort.

Methods

Participants

In this cross-sectional research design, 53 elite female netball athletes (mean \pm SD; age 24 ± 3.9 years) were recruited from one elite netball competition; the ANZ Premiership League (New Zealand), which is widely considered as one of the leading domestic netball competitions in the world. Approximately 25 of the 53 participants have represented their country internationally within the 2020/21 Silver Ferns squads, with all 53 participants playing netball professionally in the national competition (ANZ Premiership Competition). Ethics approval for this study was obtained through the Institution's Human Research Ethics Committee (HREC(Health)2020#52). All participants provided their informed consent at the beginning of the questionnaire as well as a second confirmation of consent by the action of pressing "submit" at the completion of the questionnaire.

Study Design

The participants were required to complete an adapted version of the LEAF-Q via a self-administered, online survey platform (Survey Monkey Inc, San Mateo, CA). The survey consisted of 29 questions, including both multichoice and short answer questions, taking approximately 10-15 minutes to complete. All participants' data were included in the final

sample size. If a participant failed to complete a question, their data may have still been used within the final sample if the incomplete question had no impact on their final risk classification. The two age groups used for analysis (18-24 and 25+ years) were chosen to replicate the ranges used in a similar study by Logue and colleagues (2019).

Measures

Low Energy Availability in Females Questionnaire (LEAF-Q)

The LEAF-Q is a validated screening tool used for identifying female athletes ‘at-risk’ of the female athlete triad and/or LEA. The LEAF-Q is utilized most commonly within elite athlete populations due to its simple implementation and the ability to detect signs and symptoms at an early stage, whilst alleviating some of the difficulties involved with measuring energy availability (EA) directly (Mountjoy et al., 2018a; Mountjoy et al., 2018b). The questionnaire produces an acceptable sensitivity of 78% and specificity of 90% to correctly classify current energy availability and/or menstrual function and/or bone health (Melin et al., 2014). Thus, the LEAF-Q provides a validated tool to determine ‘at-risk’ populations in large elite groups (Slater et al., 2016).

The LEAF-Q consists of 25 questions regarding three key areas of gastrointestinal symptoms, injuries, and menstrual dysfunction. A score of 0-49 is derived, with participant’s grouped according to their LEAF-Q score. Participant scores of ≥ 8 were classified as ‘at-risk’ of LEA, and those who scored 7 or less were classified as ‘not at-risk’ of LEA. For the current study, the LEAF-Q was modified with the addition of four sport-specific injury questions (Table 3), to aid in a better understanding of the relationship between the risk of LEA and injury occurrence. These additional questions were not included in the assessment of ‘risk’ and did not contribute to the participants’

overall risk score.

Table 3. Additional questions and answers to the Low Energy Availability in Females Questionnaire (LEAF-Q)

Questions	Answers
If you have sustained an injury in the past 1.5 years; did this occur during a netball training or game?	Yes or no
If yes to previous question, how did the injury occur?	Sharp turn/change of direction, collision with opponent, hyperextended, incorrect landing, collapsed, fall, overuse, other (explain)
Incidence of injury; was this injury...	New (first time), chronic (overuse), recurrent (repeated)
Did this injury require surgery?	Yes or no

Statistical Analysis

Means, standard deviations, maximum values, and percentages presented as results were calculated using Microsoft Excel (version 16.37 20051002, Microsoft Excel, 2020). For categorical data, results were expressed as absolute numbers (*n*) and percentages (%).

A Student's paired *t* test was used to compare differences between the risk classifications and age groups using the Statistical Package for Social Science (SPSS 27.0 IBM Corp, Armonk, NY, USA), with statistical significance set at $p \leq 0.05$. Logistic regression analysis was performed to assess the impact of LEA on variables such as incidence of injury. These were expressed as odds ratios (OR) and 95% confidence intervals (95% CI).

Results

Participant Characteristics

The characteristics of the 53 participants included in this study are presented in Table 4. There were no significant differences in the hours of training per week between risk classification, $p = >0.05$ (Table 4). However, there was a significant difference observed in both age groups (18-24 and 25+ years) between the ‘at-risk’ and ‘not at-risk’ categories. No significant differences were observed between the two age groups within the respective risk categories.

Table 4. Mean SD values for the characteristics of elite female netballers associated with risk of LEA ($n=53$)

	Total participants ($n=53$)	At risk of LEA ($n=28$)	Not at risk of LEA ($n=25$)
	<i>n</i> (%)	<i>n</i> (%)	<i>n</i> (%)
Height (cm)	180.7 ± 6.5	180.1 ± 5.9	181.4 ± 7.3
Weight (kg)	79.1 ± 13.5	79.4 ± 9.3	81.1 ± 11.5
Age group (y)			
18-24	34 (64.2)	20 (71.4) [#]	14 (56)
25+	19 (35.8)	8 (28.6)	11 (39.3) [^]
Hours of training per week (hours)	18.0 ± 4.7	18.5 ± 5.1	17.5 ± 4.3
Oral contraception use	36 (68)	21 (75)	15 (60)

[#]significant difference between risk classifications in 18-24 year olds ($p < 0.05$)
[^]significant difference between risk classifications in 25+ year olds ($p < 0.05$)

Low Energy Availability in Females Questionnaire (LEAF-Q) Scores

Over half (52.8%, $n= 28$) of participants were classified as being ‘at-risk’ of LEA according to the LEAF-Q scoring system. The participants LEAF-Q scores ranged from 0 to 20 with the total average score from all participants (100%, $n= 53$) being above the cut-off threshold at 8.3. A significant difference was observed between the two groups, with the ‘at-risk’ of LEA group scoring substantially higher than the group ‘not at-risk’ of LEA ($p < 0.01$, Table 5).

Table 5. Mean \pm SD values for associated scores from the three LEAF-Q categories in elite female netballers

	At risk of LEA ($n=28$)	Not at risk of LEA ($n=25$)
Injury	3.25 \pm 2.30 [#]	1.28 \pm 1.74
Gastrointestinal Function	3.21 \pm 2.41 [#]	1.48 \pm 1.50
Menstrual Function	4.70 \pm 2.70 [#]	2.36 \pm 1.68
Total Score	11.14 \pm 2.89 [#]	5.12 \pm 2.07

[#]significantly different score from ‘not at-risk’ ($p < 0.05$)

Menstrual Function

The ‘at-risk’ group significantly scored more than double that of the ‘not at-risk’ group for menstrual function ($p < 0.01$, Table 5).

As part of the LEAF-Q, participants were asked if they felt as though they had normal menstruation. Thirty-eight (52.8%) said yes, 13 (24.5%) said they do not have normal menstruation, and two (3.8%) said they did not know whether they had normal menstruation. Out of the 13 who felt as though they do not have normal menstruation, 10

(76.9%) were classified as ‘at-risk’ of LEA. In addition, 36% of participants ($n=19$) reported a change in menstrual cycle related to increased intensity or frequency of exercise.

Of the 36 participants currently using an oral contraceptive or any other hormonal contraceptive, 13 (36.1%) reported that they did not currently have normal menstruation. Of the 13 females with abnormal menstruation, five stated that they have not had a period for 6 months or more, with the remaining eight experienced their last period 2-3months ago. Of the two participants who responded “I don’t know” to having normal menstruation, one has not had a period in 6 months or more, with the other not having a period for 2-3months.

The percentage of those considered ‘at-risk’ of LEA differed slightly when contraceptive users were excluded from the analysis. Risk of LEA was identified in 41% of participants ($n=17$, excluding contraceptive users) compared to 53% ($n=53$, including contraceptive users). Seventy-five percent of ‘at-risk’ of LEA participants reported using either an oral contraceptive or another form of hormonal contraception (e.g. intrauterine device [IUD], Depo Provera injection, Levonorgestrel [Jadelle] implant).

Injury

‘At-risk’ participants reported a much higher incidence of injury within the last 12 months compared to that of the ‘not at-risk’ group (Table 6). Although not statistically significant, the risk of LEA was close to five times more likely to occur among participants who experienced an injury within the past 12 months compared to those who reported no recent injury ($p = 0.21$; Table 6).

Much like menstrual function, the 'at-risk' population scored more than double than the 'not at-risk' group within the injury section of the LEAF-Q (Table 5). Table 6 displays the reported days absent due to injury, the commonly reported injuries and the incidence of injuries within the last 12 months. A total of 50 injuries were reported, over half of these injuries occurring within the 'at-risk' group (Table 6). The 'at-risk' group had more injuries in all categories except tendon and muscular injuries. The 'not at-risk' group reported a larger number of (first time) injuries, whereas the 'at-risk' group reported more recurrent and chronic injuries. Out of the total 38 participants who experienced an injury in the past 12 months, 74% ($n=28$) of these injuries occurred during a netball training or game.

Gastrointestinal function

Almost 25% of total participants ($n=53$) reported gaseous and/or bloating symptoms not related to their menstrual cycle, either several times a day or several times a week. In addition, 78.6% ($n=22$) of 'at-risk' participants reported experiencing gaseous and/or bloating symptoms once or twice a week, or several times weekly or daily (Table 6).

Table 6. Self-reported injuries, incidence, absence due to injuries and gastrointestinal function in elite female netballers

	At risk of LEA (n =28)	Not at risk of LEA (n =25)	OR
	<i>n</i> (%)	<i>n</i> (%)	
No. of participants with injuries^a	24 (85.7%)	14 (56%)	4.7 (1.26-17.67)
Reported days absent due to injury^b			
1-7 days	10 (35.7%)	7 (28%)	1.4 (0.45-4.59)
8-14 days	5 (17.9%)	1 (4%)	5.2 (0.57-48.13)
15-21 days	2 (7.1%)	2 (8%)	0.9 (0.12-6.80)
≥ 22 days	6 (21.4%)	1 (4%)	6.5 (0.73-58.76)
Commonly reported injuries^c			
Ligament	10	7	N/A
Tendon	3	5	N/A
Muscular	6	7	N/A
Cartilage	5	0	N/A
Concussion	1	0	N/A
Stress fracture	4	1	N/A
TOTAL	29	21	
Incidence of injury^d			
New	8	9	N/A
Recurrent	9	5	N/A
Chronic	3	1	N/A
Gaseous/bloated not related to menstruation			
Never	6 (21.4%)	16 (64.0%)	N/A
Once or twice a week	13 (46.4%)	5 (20.0%)	N/A
Several times daily/weekly	9 (32.1%)	4 (16.0%)	N/A

Note: LEA: low energy availability, OR: odds ratio (presented as OR (95% CI).

^a Number of participants with injuries within the last 12 months.

^b Reported absences from training or competition within the last 12 months.

^c The *n* value represents the number of the particular injury reported (respondents may report more than one injury category).

^d Respondents could choose more than one answer if they had more than one injury within the last 12 months.

Discussion

To the best of our knowledge, the present study is the first to investigate the prevalence of LEA in elite female netball athletes. The overarching finding from this study was 53% ($n=28$) were classified 'at-risk' of LEA via the LEAF-Q. Significant differences were observed for all three LEAF-Q categories (injuries, gastrointestinal function & menstrual function) between the 'at-risk' and 'not at-risk' groups (Table 5). Furthermore, nearly 86% of those 'at-risk' of LEA reported experiencing one or more injuries within the recent 12 months.

The proportion of elite female netballers considered 'at-risk' of LEA in this study (53%) aligns with literature previously reported. Also implementing the LEAF-Q to identify prevalence in elite team sport athletes, Christensen (2019) found 55% ($n=20$) of elite rugby 7's athletes were 'at-risk' of LEA. Although there are parallel results of the current study compared to Christensen (2019), we were able to investigate risk of LEA in a larger sample size than the elite rugby 7's athletes. Therefore, our larger sample size may be a more reflective and an accurate representation of elite team sport populations that use the LEAF-Q to assess LEA. To add, Braun and colleagues (2018) found 53% ($n=56$) of elite youth football players exhibited LEA. Although the preceding results may seem comparable, the different methods in determining LEA could produce different results. For example, Braun and colleagues (2018) used diet and activity logs to calculate EA compared to Christensen (2019) and the present study which used the LEAF-Q. Future research should aim at replicating similar methodologies to accurately compare LEA risk or prevalence between varied team sports. Furthermore, as displayed in the previous literature and the current study, our results dispute the common idea that LEA is primarily experienced within endurance/individual sporting populations. Further research is

required to investigate whether other elite team sport populations are at a similar risk of developing LEA compared to the sports commonly reported in the past.

In regards to menstrual function, it was unsurprising to observe over a third of participants reported that their menstruation cycle changes when they increase the intensity or frequency of exercise, as this is a reflection of how energy sensitive the reproductive system is; with 14 of those who stated they experience a change in their cycle due to an increase in exercise being classified as 'at-risk' of LEA. Almost 30% of these 'at-risk' participants stated that their menstruation stops as a result of increased frequency or intensity of exercise. These findings are consistent with recent research that indicates 20.2% of ultra-marathon runners experience cessation of their menstrual cycle due to an increase in exercise intensity or frequency (Folscher et al., 2015). Comparably, Heather et al. (2021) reported 32% of elite level female athletes from New Zealand felt their menstrual cycle was affected by training volume, with associated outcomes including less regular cycles (14%, $n=23$), more regular (31%, $n=36$), shorter menses (17%, $n=20$), and more (30%, $n=35$) or less blood loss (20%, $n=23$).

It is well known that secondary amenorrhea associated with exercise commonly occurs when chronic inadequate or restricted dietary intake does not account for the increased frequency and/or intensity of exercise (Logue et al., 2018; M. Warren, 1999). The development of exercise-induced amenorrhea opens up a plethora of significant risks and negative influences for the individual, including hypoestrogenism (oestrogen deficiency), osteoporosis and risk of stress fractures, with concerns of fertility issues additionally. Secondary amenorrhea is correlated with the most severe oestrogen deficiencies, with the most harmful effects on skeletal health compared to other forms of menstrual disturbances

(De Souza & Williams, 2005). Hypoestrogenism is one of the main contributing factors to bone mineral density (BMD) loss and osteoporosis, often described as an imbalance between bone formation and bone resorption (Suri & Altshuler, 2007). In the current study, only 9.4% ($n=5$) of participants reported a recent stress fracture within the past year, however, 80% ($n=4$) of these stress fractures were suffered by participants classified as 'at-risk' of LEA. Previous research has shown that weight bearing activities and frequent mechanical loading are an important determinant for bone density (Pettersson et al., 2000). Netball has a high mechanical loading stimulus and is characterised by running, directional changes and repetitive jump-landing movements (Chang et al., 2013). Otago (2004) reported the ground reaction forces when playing netball were between 3.5 and 5.7 times body weight (Otago, 2004), which, according to Frost (1988) exceed the threshold of mechanical loading required to promote beneficial bone health effects (Frost, 1988). Therefore, giving reason as to why the current study population did not report as many bone stress injuries, due to the mechanical load required in netball. Whilst the occurrence of stress fractures in our cohort were minimal, the results still coincide with previous literature that reports a higher rate of bone injuries in athletes with LEA, amenorrhoea, and oestrogen deficiencies (De Souza & Williams, 2005; Slater, 2015).

It has been reported that approximately 55% of amenorrheic women display severe oestrogen deficiencies, which is a major cause for concern considering the negative consequences that may equate whilst in a state of amenorrhea (Miller & Klibanski, 1999; Stanley, 2019). The first long term study by Keen and Drinkwater (1997), investigated BMD in amenorrhoeic athletes. The authors concluded that those who previously displayed amenorrhea but have since had years of normal menses continued to exhibit significantly lower BMD at the lumbar spine, in comparison to athletes who have always

had regular cycles. This finding suggests that there are major threats of irreversible bone loss and osteoporosis for athletes with amenorrhea. The current study identified that 11% ($n=6$) of participants who reported abnormal menstruation, had their last period 6+ months ago, which may indicate functional hypothalamic amenorrhea (McIver et al., 1997). Though, these athletes were all currently using a form of contraception which could have induced amenorrhea not related to exercise or LEA. As the LEAF-Q is only designed as screening tool, it does not provide further question for clarity surrounding abnormal menstruation and whether contraceptive use had any influence on their answer.

In the present study, 14 out of the 17 (82.4%) participants not currently using a form of contraceptive were classified as eumenorrheic due to their self-reported timing of last period. However, five of the 14 participants were ‘at-risk’ of LEA based on their answers to the other sections in the LEAF-Q. This may indicate that although eumenorrheic, they are likely ‘at-risk’ due to injury or gastrointestinal issues. In addition, ten participants who were ‘at-risk’ of LEA scored 12 or more in the LEAF-Q. This suggests that these participants may be experiencing multiple concerning variables across the three categories (menstrual function, injury, gastrointestinal function) which contributed to their high ‘at-risk’ score. It is important to note that not all participants classified as ‘at-risk’ of LEA will display signs of menstrual dysfunction, and vice versa not all athletes with menstrual abnormalities will be in a state of LEA (Slater, 2015). For example, LPD or anovulation may present without changes to cycle length, thus, an individual may be experiencing menstrual cycle disturbances but be unaware due to the lack of symptoms (Loucks et al., 2011; Loucks & Thuma, 2003; Mallinson & De Souza, 2014; Slater, 2015).

The most common injury category within this cohort were ligament injuries with 17

injuries in total throughout the whole group, accounting for 34% of all injuries reported. This result is not surprising as the rapid accelerations, decelerations and frequent change of direction movements required in netball causes a high injury risk to the lower extremities. In particular, causing the ankle and knee to be frequently referenced as the most prevalent areas for soft tissue injury within netball (Belcher et al., 2020; Joseph et al., 2019). Interestingly, in 2016, ligament/sprain damage accounted for 57% of all netball injury claims in Australia, with the ankle and knee constituting of 47% of all netball injury claims in New Zealand for the year of 2017 (Belcher et al., 2020; Joseph et al., 2019).

It is well documented that LEA and menstrual dysfunction contributes to impaired bone health, most commonly seen in female athletes (Ducher et al., 2011; Melin et al., 2019; Nattiv et al., 2007; Petkus et al., 2017). Previous research has demonstrated decreased BMD, bone strength and an increased risk of bone stress injuries in athletes with diagnosed LEA or oligo-/amenorrhea, compared to those who are eumenorrheic and/or in an energy balance (Mountjoy et al., 2018a; Nattiv et al., 2007). Furthermore, according to Nose-Ogura and colleagues (2019), female athletes who display one of the three components of the female athlete triad; disordered eating, amenorrhea and osteoporosis are 2.5 times more likely to develop stress fractures than athletes with no components of the Triad (Nose-Ogura et al., 2019). As mentioned previously, the current study discovered only 9.4% ($n=5$) of participants reported a recent stress fracture within the past year, with 80% of these participants being classified as 'at-risk' of LEA. These findings align with the concept by Nose-Ogura and colleagues (2019) that there are associations between bone injuries in female athletes displaying LEA or components of the female athlete triad (Nose-Ogura et al., 2019). Similarly, in a study involving recreational exercising females, only 4% ($n=4$) of participants reported a stress fracture

within the recent 12 months (Slater et al., 2016). Conversely, previous studies among endurance runners and track and field athletes have reported a greater prevalence of stress fractures ranging from 8.3% to 52% (Bennell et al., 1996; Day et al., 2015; Fredericson et al., 1997; Nattiv, 2000). Variability in mechanical loading among different sports is important to consider when investigating bone stress injuries, as some sports require higher impact and repetitive loading than others, which is likely to be a factor in sporting populations displaying varied incidence rates of stress fractures (Beals & Hill, 2006; Day et al., 2015; Javed et al., 2013).

Concerningly, over 70% of the total participants in the present study experienced at least one injury within the last 12 months. These results are higher than previously reported in recent literature that indicate 58.7% of recreational (Slater et al., 2016) and 59.1% of endurance trained athletes (Folscher et al., 2015) experienced at least one injury per year. Furthermore, 66% of total participants in the current study reported an absence from training due to an injury within the recent 12 months. These findings coincide with a recent study in a large cohort investigating various levels of athletes participating in a range of sports or physical activity, which reported that 62% of subjects reported an absence from training due to a recent injury (Logue et al. (2019). In addition, in our study, the 'at-risk' of LEA participants were 6.5 times more likely to have an absence of 22 or more days due to injury compared to the 'not at-risk' of LEA participants. Therefore, potentially indicating that those 'at-risk' are more likely to suffer injuries of a higher severity, requiring longer rehabilitation compared to those 'not at-risk'.

Previous clinical data indicates that athletes who are in a state of LEA will commonly experience high frequencies of gastrointestinal disturbances (Lis & Gaskell, 2019).

Although this variable is not well researched, it is well known that dietary intake can influence adverse gastrointestinal symptoms (Lis & Gaskell, 2019). Although limited, previous research suggests that gastrointestinal symptoms are estimated to occur in approximately 30-70% of athletes (Costa et al., 2017; Lis & Gaskell, 2019). The aforementioned studies display higher percentages than reported in the present study; just under one-quarter of our cohort reported gaseous and/or bloating symptoms not related to their menstrual cycle, either several times a day or several times a week. Similarly, Folscher et al. (2015) reported that 14.7% of endurance ultra-marathon athletes experience bloating and gaseous symptoms daily/weekly not related to their menstrual cycle, which is very low compared to the 85% of ultra-marathon runners with gastrointestinal symptoms reported by Costa and colleagues (Costa et al., 2016). Although a predominant risk factor for LEA (Mountjoy et al., 2014), the variability and differences in gastrointestinal symptoms in athletes shows that it is not a well-documented variable, which highlights the need for future research in this area.

A limitation of the current study is that the screening tool (LEAF-Q) used to identify the risk of LEA was validated in endurance-trained athletes only (Melin et al., 2014). The LEAF-Q needs to be further evaluated in other various athletic groups to ensure its validity in other sports. Furthermore, the LEAF-Q measures the 'risk' of LEA and does not serve as a diagnosis. To provide a true and accurate result of the presence of LEA in elite female netballers, metabolic markers and hormonal measures would need to be taken (Slater, 2015). Thus, further research is warranted to diagnose LEA within this population, especially when considering the large percentage of 'at-risk' participants identified by our study. However, the strengths of this study include being able to investigate an elite athlete population. Furthermore, our sample size is larger than most previous elite team

sport athlete studies (Christensen, 2019; Dobrowolski & Wlodarek, 2020; Groom, 2019; Reed et al., 2013).

Conclusion

In summary, the results of the current study showed that risk of LEA occurred among 53% of our cohort of elite female netballers, with a substantial percentage of the 'at-risk' group experiencing an injury within the last 12 months (85.7%). We acknowledge that there are various indicators and contributing factors in the development LEA, and is not limited to the three areas covered in the LEAF-Q (Rogers et al., 2021). LEA is an evolving term with research over time advancing the impacts and consequences involved within this condition. Thereby, further research is warranted to investigate the additional factors contributing to LEA in this population. Moreover, a clinical diagnosis would be beneficial to these athletes, as the known outcomes of LEA are severe and pose long term negative health consequences. There is a clear prevalence of LEA in elite female netballers, therefore sport practitioners working within this population should consider the inclusion of monitoring LEA signs and symptoms into their regular health monitoring, to ensure immediate implementation of intervention and, more importantly, diagnosis does not go undetected.

**Chapter Three – Summary, Limitations, Strengths, Practical
Applications and Future Research**

Summary

The first chapter of this thesis comprised of a literature review, which examined the current research surrounding LEA, the outcomes associated, the prevalence in various sports and athletes, the methods used to detect LEA and physician awareness. It is known that LEA is associated with an expansive range of negative health impacts, including skeletal health, reproductive dysfunction, gastrointestinal issues, cardiovascular health, immune functions and psychological impairment (Sundgot-Borgen & Garthe, 2011), all of which can pose detrimental effects to athlete performance. LEA and the association of bone injuries has been well documented, with known correlations between increased risk of bone stress injuries in athletes with menstrual dysfunction and amenorrhea in particular. However, the association of LEA and soft-tissue injuries is not well known at present and requires future research to discover whether any relationship exists between LEA and any non-skeletal injuries. The prevalence of LEA varies greatly among current literature, with a variance of 2-100% observed in different sports, level of competition and populations. The majority of literature to date has focused on “high risk” sports such as endurance athletes, with little insight into team sport athletes until recently. There is currently no gold standard assessment or screening tool for LEA, which makes it difficult to compare studies using differed methods to calculate LEA. There is a lack of consensus on which tool has the best efficacy, and due to the complicated nature of the components of LEA there is yet to be one method developed that is both practical and reliable. Coach and physician awareness of LEA is poor, with previous literature reporting up to 85% of coaches had never heard of LEA or the Female Athlete Triad (Mukherjee et al., 2016).

The prevalence of LEA in team sport populations is at present a relatively small research area. Therefore, the aim of the original study in Chapter Two was to investigate the

prevalence of those classified as ‘at-risk’ of LEA in elite female netball athletes using the Low Energy Availability in Females Questionnaire (LEAF-Q). The main finding from this study showed that 53% of participants were classified as being ‘at-risk’ of LEA. A secondary finding from the study was a significant difference observed between the ‘at-risk’ group versus the ‘not at-risk’ group for all three LEAF-Q categories (gastrointestinal function, menstrual function and injuries). Furthermore, findings showed that 85.71% of ‘at-risk’ participants reported sustaining an injury within the past 12 months, with risk of LEA being 4.7 times more likely to occur among participants who experienced an injury within the recent year compared to those who reported no injury. The current study indicates that there is a large prevalence of LEA in elite netballers, which is a population to the authors’ knowledge that has not previously been studied. The team sport population has largely been underrepresented in LEA literature, however the results from the current study and fellow studies in Football and Rugby Seven’s cohorts warrants the need for further research of LEA, which will add to the previous literature on endurance sport athletes.

Limitations

- Although providing an acceptable sensitivity and specificity of 78% and 90% respectively, the LEAF-Q still shows potential for misclassification. Additionally, the self-reported nature of questionnaires can enhance the risk of respondent bias, with athletes’ responses being subjective and influenced by perception of questions.
- It may be possible that some athletes did not answer truthfully to avoid being classified as ‘at-risk’ of LEA, and the subsequent impact this may have on them as an athlete. Therefore, it is possible our results may have underestimated the

prevalence of LEA. We did however implement steps to encourage athletes to respond truthfully. These included having the New Zealand Netball Players Association distribute the electronic link to complete the questionnaire, thus being independent of any organisation. Further, participants were able to nominate their preferred medical professional to receive their result from, ensuring medical confidentiality.

- The additional four questions included in the present study were not validated, however allowed for further investigation surrounding the epidemiology of the injuries, as the original questionnaire injury section lacked specificity.
- The LEAF-Q has some drawbacks, with several questions lacking clarity and information for the researcher. For example, participants are asked whether they have ‘normal’ menstruation, if they answer ‘no’ or ‘I don’t know’, it does not provide further questioning in regard to why the participant feels as though their menstruation is not normal. The injury section provides limited information also, having to rely heavily on the participant providing enough information in the ‘what kind of injuries have you had in the last year?’ question. Participants may not provide correct injury terminology or provide enough information overall. E.g. only providing ‘ligament’ or ‘sore hip’ to describe their injury. Therefore, questions that prompt additional information and require participants to provide specificity would be helpful for the researcher to gain a better understanding of the subject’s situation.
- The LEAF-Q is purely a screening tool and not developed to diagnose LEA. Despite this, it would be beneficial to the researchers if the questionnaire allowed space for clarity with addition of further questioning in some sections, to allow researchers to draw clearer conclusions about the participant.

- The age of the questionnaire may also be a limitation of this study. Although created in 2013 (Melin et al., 2014), the LEA condition is continuously developing and has since grown into a complex model which can result in many health implications, not only limited to the three categories (injuries, gastrointestinal function and menstrual function) covered within the LEAF-Q. The current format of the LEAF-Q has the potential to misclassify participants as ‘not at-risk’ because of the focus on only the three categories mentioned above, excluding athletes that are experiencing other symptoms not reflected in the questionnaire. Misclassification could potentially be dangerous and harmful to an athlete, as early detection and intervention is crucial to decrease the chances of long-term effects associated with LEA.
- All participants in the present study are elite female netballers; therefore, the results can only be indicative and a true representation of this population.

Strengths

- Despite the previously mentioned limitations of the LEAF-Q, it is also a strength of the current study as it is commonly used within large populations, it is easy to implement and removes the invasive nature of regular blood sampling and repeated hormonal measures which is not always possible at the elite level (Groom, 2019).
- Another strength of the current study is the relatively large sample size and level of athletes classified as elite that were recruited, given the small pool of professional netball athletes available to recruit from in New Zealand

Practical Applications

The findings of the current study highlight the importance of coaches, sport practitioners and athletes needing to be aware of LEA and the impact LEA has on overall health. As shown in Chapter One, LEA knowledge and awareness in coaches and physicians is poor. Therefore, educating and increasing coaches, sports practitioners, and support staff working with elite athletes understanding on the signs and symptoms of LEA is the first step in enabling early detection, diagnosis and relevant intervention to occur. Where possible, it would be recommended that sport practitioners working within elite athlete populations consider the inclusion of monitoring common signs and symptoms of LEA to ensure immediate mediation. Specifically, menstrual tracking may be a useful monitoring tool to start with, as the current study and previous research highlight that changes in menstrual function are one of the first signs LEA may be present. Furthermore, educating athletes on the effects of LEA and providing services could be advantageous in the prevention of LEA.

Future Research

- To our knowledge, the current study is the first to investigate the prevalence of low energy availability in elite female netball athletes. Therefore, future research investigating performance measures within this cohort would be of interest to understand the prevalence of LEA and potential effects on performance in this population.
- As the LEAF-Q is currently only validated in endurance athletes, it would be advantageous for the LEAF-Q to be validated in team sport athletes in the future.

- The LEAF-Q is a screening tool to provide an indication of risk, and not to be used as a form of diagnosis of LEA. Therefore, future research should consider using resting metabolic rate (RMR) tests, hormonal measures and hormonal markers in addition, which will allow for a true and accurate presentation of LEA within this population whilst providing a diagnosis which will be beneficial for these athletes.
- Future research investigating recreational, high school level and development netball athletes would be beneficial to see the prevalence of LEA in these populations. Furthermore, it would be interesting to investigate whether prevalence of LEA increases as the level of competition increases.
- Findings in the current study highlight the ‘at-risk’ participants suffered more ligament related injuries than ‘not at-risk’, however research is yet to investigate soft-tissue injuries in detail and assess whether there is any correlation present between participants with LEA and injuries soft-tissue in nature, therefore warranting future research in this area.

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Appendices

Appendix A - Ethics Approval

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

Human Research Ethics Committee
Roger Moltzen
Telephone: +64021658119
Email: humanethics@waikato.ac.nz



THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

9 September 2020

Courtney Davie
Te Huataki Waiora School of Health
DHECS
By email: courtneynz13@hotmail.co.nz

Dear Courtney

HREC(Health)2020#52 : Prevalence and Impact of Low Energy Availability in Elite Female Netballers

Thank you for your thorough responses to the Committee's feedback. I am happy to give ethical approval for this research to commence, **conditional** upon obtaining approval from Netball NZ. **We also require a copy of this approval for our records.**

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

We wish you all the best with your research.

Regards,

A handwritten signature in black ink, appearing to be 'RM' or similar initials.

Emeritus Professor Roger Moltzen MNZM
Chairperson
University of Waikato Human Research Ethics Committee

Appendix B – Netball New Zealand Support Letter



October 21st 2020

Dear Shannon,

I write to confirm Netball New Zealand (NNZ) support for the proposed research project entitled *“Prevalence and Impact of Low Energy Availability in Elite Female Netballers”*.

As part of our support we will make our semi-professional playing population (ANZ Premiership and Silver Ferns players) available to the researchers should they wish to volunteer to participate.

As discussed recently, given the high profile nature of a number of the potential participants and the personal nature of the proposed data collection, we request the following safeguards are in place for the participants as part of the research methodology.

1. Only one researcher has access to the identified data for the purposes of reporting and follow up with the player (if required). All other researchers only have access to the deidentified data.
2. That the researcher with this access is one of the senior searchers on the project.
3. That players are able to nominate that if necessary findings are either reported to the NNZ Medical Director or a nominated GP. We anticipate this will be required if that individuals results indicate that clinical follow up is required.

NNZ sees significant value in this project and we are looking forward to working with you on player education as part of the project. We also ask that when appropriate results are shared with NNZ and the New Zealand Netball Players Association (NZNPA) to ensure we can use these to inform future initiatives to support players well-being and performance.

Thank you once again for involving us in this project and your patience while we have worked through the process to this point.

Sincerely,

Keir Hansen
Head of High Performance

Appendix C - Consent Form

Consent form

Project Title: Prevalence and Impact of Low Energy Availability in Elite Female Netballers.

Researcher: Courtney Davie

Supervisors: Shannon O'Donnell & Matthew Driller

By pressing "submit" at the conclusion of this survey; I _____ agree to participate as a volunteer in a scientific investigation as an approved part of a research program at the University of Waikato under the supervision of _____.

The investigation and my part in the investigation have been defined and fully explained to me by _____ and I understand the explanation. A copy of the procedures of this investigation and a description of any risks and discomforts have been provided to me and discussed in detail with me.

- I have been given an opportunity to ask whatever questions I may have had, and all questions have been answered to my satisfaction.
- I understand that the data collected in this research project may be reported in scientific publications, presentations, teaching, and student theses.
- I understand that I am free to withdraw from the project and ask for my data to be destroyed within a 3-week period after the research activities, without disadvantage to myself.
- I understand that my data will be anonymized through a coding system, to protect my identity in the research reporting.
- I am participating in this project of my own volition and I have not been coerced in any way to participate.
- I am free to ask for a cultural advisor at any point during the study.

Date: ____/____/____

I, the undersigned, was present when the study was explained to the subject/s in detail and to the best of my knowledge and belief it was understood.

Signature of Researcher: _____

Date: ____/____/____

Contact Details for Researchers:

Courtney Davie (Primary Investigator)

courtneynz13@hotmail.co.nz | 0278298692

Shannon O'Donnell (Supervisor)

shannon.odonnell@waikato.ac.nz | 0274239752

Appendix D – Participant Information Sheet

Participant Information Sheet



Project Title – Prevalence and Impact of Low Energy Availability on Elite Female Netballers.

Purpose – Discover prevalence of low energy availability in elite female netballers and correlating impacts on performance.

Background – Low energy availability (LEA) is the underlying cause of both the Female Athlete Triad (FAT) and Relative Energy Deficiency in Sport (RED-S). Both have been described as syndromes correlating with negative health consequences observed in athletes, most commonly female athletes. The aim of this project is to gain an understanding on the prevalence of LEA in elite female netballers and the impact it has on physiological functions, performance, and injury. We are looking to discover whether individuals classed at high risk for low energy availability are more susceptible to injury than that of an individual classed as low risk.

Overview – Should you agree to participate, you will be asked to complete an informed consent form at the beginning of the survey provided to you via an online platform Survey Monkey. You will be asked to then complete a questionnaire known as the low energy availability in female's questionnaire (LEAF-Q) which will take no longer 15 minutes to complete. The questionnaire consists of questions related to the following topics; injuries, gastrointestinal function and menstrual function.

Potential risks – There are no potential risks involved within this project as it purely involves the completion of an online questionnaire. The LEAF questionnaire does not pose any harm towards participants, it is a validated survey commonly used throughout the athlete population to identify low energy availability. The nature of the questionnaire is non-invasive and is completed voluntarily at their discretion.

Potential benefits – Benefits of participating within this study include gaining individualised feedback based on your results of the LEAF-Q, and what this means for your performance and physiological functions as an elite netballer.

What will happen to the information collected – The information collected will be used by the research team to write research reports, master's theses and potential oral presentations. Only the research team will have direct access to any notes and documents. At the end of the project, any personal information will be destroyed immediately except that, as required by the University's research policy, any raw data on which the results of the project depend will be retained in secure storage for five years, after which they will be destroyed. All data will be treated with the strictest confidentiality. No participants will be named in the publications and every effort will be made to disguise their identity. All data used will be de-identified to protect your identity and confidentiality.

Participation and withdrawal – Participants are free to withdraw from the study at any time, and information provided up until three weeks after data collection.

Declaration to participants – If you take part in the study, you have the right to:

- Refuse to answer any particular question, and to withdraw from the study before analysis has commenced on the data.
- Ask any further questions about the study that occurs to you during your participation, at any time.
- Be given access to a summary of findings from the study when it is concluded.
- Participants are welcome to ask for a cultural advisor at any time if they wish.

Who's responsible – If you have any questions about the project, please feel free to contact:

Courtney Davie (**Primary Investigator**) and Shannon O'Donnell (**Supervisor**)
The University of Waikato – Te Huataki Waiora / School of Health
Courtneynz13@hotmail.co.nz Shannon.odonnell@waikato.ac.nz

Appendix E – The Low Energy Availability in Females Questionnaire

October 30, 2013 [THE LEAF-Q]



(Supplemental Digital Content 1)

The LEAF-Q

A questionnaire for female athletes

Department of Nutrition, Exercise and Sports
Life Science
University of Copenhagen
Denmark

Contact: Anna Melin, aot@life.ku.dk

The low energy availability in females questionnaire (LEAF –Q), focuses on physiological symptoms of insufficient energy intake. The following pages contain questions regarding injuries, gastrointestinal and reproductive function. We appreciate you taking the time to fill out the LEAF-Q and the reply will be treated as confidential.

Name: _____

Address: _____

E-mail: _____

Cell: _____

Profession: _____

Education: _____

Age: _____ (years)

Height: _____ (cm) Weight: _____ (kg)

Your highest weight with your present height: _____ (kg)
(excluding pregnancy)

Your lowest weight with your present height: _____ (kg)

Do you smoke? Yes No

Do you use any medication (excluding oral contraceptives)? Yes No

If yes, what kind of medication? _____

Your normal amount of training (average) – number of hours per week and what kind of exercise, such as running, swimming, bicycling, strength training, technique training etc.:

Comments or further information regarding exercise: _____

1. Injuries

Mark the response that most accurately describes your situation

A: 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, three or four times Yes, five times or more

A1: If yes, for 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

A2: If yes, what kind of injuries have you had in the last year? _____

Comments or further information regarding injuries: _____

2. Gastro intestinal function

A: Do you feel gaseous or bloated in the abdomen, also when you do not have your period?

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

B: 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

C: 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

D: How would you describe your normal stool?

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

Comments regarding gastrointestinal function: _____

3. Menstrual function and use of contraceptives

3.1 Contraceptives

Mark the response that most accurately describes your situation

A: Do you use oral contraceptives?

- Yes No

A1: If yes, 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 _____
- _____

A2: If no, have you used oral contraceptives earlier?

- Yes No

A2:1 If yes, when and for how long? _____

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

- Yes No

B1: If yes, what kind?

- Hormonal patches Hormonal ring Hormonal coil Hormonal implant Other
- _____

3.2 Menstrual function

Mark the response that most accurately describes your situation

A: 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 menstruated (If you have answered "I have never menstruated" there are no further questions to answer)

B: Did your first menstruation come naturally (by itself)?

- Yes No I don't remember

B1: If no, what kind of treatment was used to start your menstrual cycle?

- Hormonal treatment Weight gain
 Reduced amount of exercise Other
-

C: Do you have normal menstruation?

- Yes No (go to question C6) I don't know (go to question C6)

C1: If yes, when was your last period?

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

C2: If yes, are your periods regular? (Every 28th to 34th day)

- Yes, most of the time No, mostly not

C3: If yes, for how many days do you normally bleed?

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

C4: If yes, have you ever had problems with heavy menstrual bleeding?

- Yes No

C5: If yes, how many periods have you had during the last year?

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

3.2 Menstrual function

Mark the response that most accurately describes your situation

C6: If no or “I don’t remember”, 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
-

D: 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
-

E: Do you experience that your menstruation changes when you increase your exercise intensity, frequency or duration?

- Yes No

E1: If yes, how? (Check one or more options)

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