Advancing Knowledge of the Bio-Cultural Complexities of Low Energy Availability: The Value of Mixed-Methods Approaches

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Abstract: Low energy availability (LEA) is a complex health condition that most commonly affects female athletes. Research on LEA is weighted to quantitative approaches, and few studies have employed qualitative methods to understand the development of LEA. Current research fails to understand the complexity of LEA by largely operating within isolated research paradigms. This paper aims to demonstrate the value of integrating a mixed-methods research approach to understand the influence of sporting cultures on the physiological experiences of female athletes with LEA. The mixed-methods approach implemented the use of physiological (quantitative) and socio-psychological (qualitative) data obtained from elite female athletes in three sports: triathlons and running, \( n = 11 \), rugby sevens \( n = 9 \), and track cycling \( n = 10 \). The physiological data consisted of energy availability, haematological analysis, bone health, and body composition. The socio-psychological data consisted of individual semi-structured interviews with topics covering nutrition, body image, the impact of the sporting environment, and experience with LEA. The interview data were thematically analysed. By bringing qualitative and quantitative data together, this paper illustrates the complex relationship between sporting culture and the physiology of LEA. First, endurance athletes categorised as having an LEA showed a positive correlation between the relative energy intake (EI) and serum ferritin, with the interviews revealing a focus on a low body weight and reducing the EI. Second, the interviews with the rugby players showed a strong but hierarchical team culture, with the experienced players monitoring and controlling the EI of novice players. Third, among the cyclists, the EI was reduced in those categorised as having an LEA, with the interviews revealing a coach–athlete power relationship impacting dietary behaviours. To conclude, this paper demonstrates how mixed methods are important for capturing how different sporting cultures impact athletes’ socio-psychological and physiological experiences of LEA.

Keywords: relative energy deficiency in sport; female; athletes; endurance; cycling; rugby

1. Introduction

Low energy availability (LEA) is defined as a state in which the body does not have enough energy to support all the physiological functions needed to maintain optimal health [1]. When LEA occurs, a range of physiological functions are impaired, and performance can be reduced [2–5]. Although there is an interaction between LEA and psychological outcomes [1], the complexity of the interaction between the physiological and socio-psychological components goes beyond what can be obtained with psychometric testing [2,6,7]. For example, questionnaire-based research using the Low Energy Availability in Females Questionnaire (LEAF-Q) [8] screens for LEA risk. Other research studies employ psychological-based questionnaires that assess mental disorders or disordered eating behaviours [9,10]. However, these questionnaires tend to focus on diagnosing the individual athlete, and rarely address the impact of the sport environment and sport cultures. As recent sociological research has illustrated, the socio-psychological experiences, as well as
the sporting cultures in which the athletes live, train, and compete, can directly impact the development of LEA [11]. Sociologists rarely consider the physiological dimensions of LEA [12], and concomitantly, few physiologists recognise the sociological complexities and the importance of the culture surrounding athletes, and how these may impact the physiological data [13,14]. Thus, a key challenge in understanding, treating, and/or preventing LEA is realising the components' interconnections in research practice.

Within medical practice, a multidisciplinary team is encouraged as part of an athlete’s recovery and return to play. However, within a research setting, the focus is rarely placed on diagnosing individuals, but is rather placed on identifying broader patterns across a sample or population. Yet, in much of this research, disciplines are often confined to silos [15]. While sports medicine research is increasingly acknowledging the importance of the broader gendered sporting culture on sportswomen’s experiences of injury (i.e., ACL and concussion) [16], the impact of the socio-cultural context on LEA remains underdeveloped. To provide advancements to the prevention and treatment of LEA, it is advantageous for researchers to incorporate other disciplines and methodologies to gain a better understanding of this complex condition.

Recently, Ackerman and colleagues [17] called for ‘a revolution in sport culture and awareness regarding energy availability’ (p. 2) that can ultimately improve the physical, mental, and performance aspects of athletes. To achieve this, careful examination and understanding of the nuanced socio-cultural, physiological, and psychological connections of LEA is imperative. For example, a recent study by McHaffie and colleagues [18] conducted a qualitative analysis to understand female football players’ and stakeholders’ perceptions of the role of nutrition in performance. The findings demonstrate different nutrition perceptions amongst players, coaches, parents, scientists, nutritionists, and medical staff. Misconceptions of nutrition and its impact on body composition, and external pressures from coaches and social media, affected players’ nutritional practices unfavourably. They concluded that the negative impact of unfavourable nutrition practices will lead athletes to LEA. However, the impact on the physiological parameters of LEA in concordance with socio-psychological experiences and sporting cultures has yet to be considered and is warranted.

To innovate the understanding of LEA and create a rapid paradigm shift to improve prevention, treatment, and recovery, it is imperative to understand how the sporting environment (i.e., team culture, relationships among athletes, coach–athlete relationships, body image ideals, values, and communication styles) impacts LEA risk. Therefore, this paper aims to use a mixed-methods research approach, which links the physiological and socio-psychological research domains, to enhance the understanding of LEA. While mixed-methods approaches are gaining popularity in sports science and medical research focused on female athlete health [19], such approaches have yet to be used in LEA research.

Selected data from three separate projects are collated in this paper. Each project used the same methodology to gather information on the physiological and socio-psychological circumstances of elite female athletes who participated in three different sports. By using these sports, the impacts of different sporting cultures and the influences they can have on developing LEA are demonstrated. The reader should aim to focus on the wider context of this paper, which is the use of mixed-methods approaches, and the advantage of using interviews with physiological measures together rather than the particulars of the two separate methodologies, which were detailed elsewhere [11,12].

2. Materials and Methods

2.1. Experimental Design

A mixed-methods approach was employed by collecting quantitative and qualitative research data [20,21]. The quantitative physiological data consisted of determining energy availability (EA), collecting blood for hormone and micronutrient analyses, and determining body composition and bone health via a dual-energy X-ray absorptiometry (DEXA). The qualitative socio-psychological data included semi-structured interviews following the
collection of quantitative physiological data. Semi-structured interviews allowed for key topics to be explored (i.e., body image, relationship with food, coach–athlete relationships, team attitudes surrounding food, weight, performance, etc.) with scope to delve deeper and follow conversational threads as they emerged. These topics were chosen as they had been previously identified in the literature as key markers of LEA (i.e., lack of menstruation, injury/illness [1]) or possible causes of LEA (i.e., abnormal eating behaviours and body composition perceptions for sport performance). The same methodology was repeated across three different sports: (i) triathlons or endurance running (categorised as endurance), (ii) rugby sevens, and (iii) track cycling. Ethical approval was gained from the University of Waikato Human Research Ethics Committee (HREC(Health)#2017-13/#2017-24/#2017-51). Informed consent was obtained from all participants involved in the study.

2.2. Participants

The participants included elite internationally competitive female athletes from three different sports: (1) 11 non-professional but internationally competitive endurance runners and triathlon (Ironman) athletes (endurance); (2) 9 professional rugby sevens players (rugby), and (3) 10 professional track cyclists (cycling) (Table 1). Inclusion criteria included being >18 years old, being free from illness and/or injury, and having experience with training and competing at an international level for their respective sport in the women’s category. Individuals who fulfilled all measures were included in the results.

Table 1. Participant demographics and body composition of athletes participating in rugby, cycling, and triathlon and endurance running (Endurance) sports (mean ± SD).

<table>
<thead>
<tr>
<th>Demographics</th>
<th>Endurance (n = 11)</th>
<th>Rugby (n = 9)</th>
<th>Cycling (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (year)</td>
<td>33.8 ± 6.6</td>
<td>21.8 ± 2.6</td>
<td>22.6 ± 4.2</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>168.0 ± 5.8</td>
<td>167.4 ± 3.4</td>
<td>171.1 ± 4.4</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>60.2 ± 7.1</td>
<td>69.2 ± 9.7</td>
<td>68.1 ± 4.5</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>21.3 ± 1.9</td>
<td>24.4 ± 2.7</td>
<td>23.2 ± 0.7</td>
</tr>
</tbody>
</table>

| Body composition              |                   |              |
| Body fat (%)                  | 18.2 ± 5.1        | 20.9 ± 1.9   | 22.3 ± 2.4       |
| Fat-free mass (kg)            | 48.3 ± 4.7        | 51.9 ± 5.8   | 54.1 ± 4.3       |

2.3. Physiological Measures

2.3.1. Energy Availability and Resting Metabolic Rate

EA was calculated using the amount of energy consumed, or the energy intake (EI), minus the amount of energy used in exercise, or exercise energy expenditure (EEE), divided by the fat-free mass (FFM), as described by Heikura et al. [22]. Overall EA was calculated from the average of the three daily EA values. EI was obtained over a consecutive three-day weighted diet record (3DDR) and analysed using FoodWorks© nutrient analysis software package (FoodWorks 9, Professional Edition, Version 9.0.3973, Xyris Software Pty Ltd., Brisbane, Australia). The EEE value for all athletes was calculated using athlete training records, training data (e.g., Watts), duration of training sessions, and perceived exertion values to determine the appropriate metabolic equivalent (MET) for the exercise completed [23]. EEE was determined following the methods described by Heikura et al. [22]; however, measured resting metabolic rate (RMR) was substituted for predicted RMR equations in the EEE equation. RMR was measured using indirect calorimetry via a ventilated hood system (Parvo Medics TrueOne 2400, Sandy, UT, USA) following recommended protocols [24]. RMR assessments were conducted the day after completing the 3DDR.
2.3.2. Haematological Measures

Venous blood samples were obtained following the RMR assessment to identify menstrual cycle phase, metabolic function, and/or iron level abnormalities based on the individual projects’ research questions. Measures of serum transferrin receptor, ferritin, iron, C-reactive protein (CRP), cortisol, oestradiol, progesterone, luteinising hormone (LH), and follicle-stimulating hormone (FSH) were determined in the endurance athletes. Measures of serum transferrin receptor, ferritin, CRP, and triiodothyronine (T3) were determined in the rugby players. Measures of progesterone, LH, ferritin, thyroid-stimulating hormone (TSH), CRP, and FSH were determined in the cyclists. All samples were analysed by a local accredited medical laboratory.

2.3.3. Body Composition and Bone Health Parameters

Body composition and bone health measures were evaluated using whole-body dual-energy X-ray absorptiometry (DXA) scans (cycling: GE Prodigy Advance, GE Healthcare, Madison, WI, USA; rugby and endurance: Hologic, Discovery A [S/N 85816] Marlborough, MA 01752). A total-body scan, in standard scan mode, was performed and analysed by the same trained technician using standardised operation and body positioning protocols. Selected body composition variables included fat mass (FM), percentage body fat mass (% FM), and FFM. Bone health parameters evaluated the bone mineral density (BMD; g/cm$^2$) at the anterior–posterior lumbar spine (L1–L4) and total hip (mean result of two femur measurements). Age- and sex-matched BMD Z-scores were derived using Australian (Combined Geelong/Lunar) male or female reference population data (v113).

2.4. Socio-Psychological Measures: Interviews

The interviews were conducted within one month of completing the physiological assessments. The interviews for the endurance athletes, rugby players, and cyclists were conducted between August 2017 and March 2018, between February 2018 and March 2018, and between November 2018 and January 2019, respectively. All interviews were semi-structured and individually audio recorded and conducted in person, except for a few interviews with rugby players that were conducted via video conferencing [11]. The interviews followed a similar structure and covered the same key topics, including body image as shaped by gendered social expectations and the high-performance sporting culture, nutritional behaviour relationships with coaches and fellow athletes, sources of social- and performance-based expectations, and past or present experience with LEA and LEA-related symptoms (Table 2). The second author, an experienced sociologist, was an integral member in all three projects in managing, collecting, and analysing the qualitative data with other members of the research teams.

<table>
<thead>
<tr>
<th>Topic Area</th>
<th>Content</th>
</tr>
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<tbody>
<tr>
<td>Low energy availability</td>
<td>Experiences, knowledge, and information sources</td>
</tr>
<tr>
<td>Menstruation</td>
<td>Menstrual cycle irregularity, source of irregularity, professional health support, perceived links to health and performance, and period pain</td>
</tr>
<tr>
<td>Body Image</td>
<td>Body changes, body relationships, and body image pressures and the sources of those pressures (both internal and external to sport)</td>
</tr>
<tr>
<td>Nutrition</td>
<td>Nutrition practices to improve health/performance, pressures, common nutritional ideas and practices within the sport, information sources, and support</td>
</tr>
<tr>
<td>Sporting Environment</td>
<td>Relationships with others (i.e., coaches, other athletes, family members, and media) and how these shaped athlete relationships with food, body image, performance, and who they talked to about health issues (including menstrual changes and other LEA symptoms)</td>
</tr>
</tbody>
</table>
2.5. Data Analysis

Statistical calculations were performed on the physiological measures using Minitab® Statistical Software (18.1; State College, PA, USA) with the level of significance set at \( p < 0.05 \). Descriptive results are presented as mean ± SD unless otherwise specified. LEA status was categorised based on values of <30 kcal/kg FFM/day. BMD was categorised using Z-scores (Z) as follows: \( Z > -1 \), normal BMD; \( Z < -1 \), low BMD; and \( Z < -2 \), clinically low BMD; osteoporosis [1]. Athletes were compared between LEA and higher energy availability (HEA; >30 kcal/kg FFM/day), or with player experience (experienced or novice; less than 1y in the elite team) using independent t-tests. A Pearson correlation coefficient quantified the relationship between energy intake and other physiological measures in endurance athletes.

All interviews were transcribed verbatim. Transcripts were sent to the athletes to check for accuracy before analysis. Interview data were analysed following the thematic analysis phases by Braun and Clarke [25] using NVivo software (Pro Version 11, QRS International Pty Ltd., Doncaster, VIC, Australia). Athlete quotes are represented by sport (E: endurance, R: rugby, and C: cycling) and participant number for anonymity.

To create greater meaning, understanding, and context of EA status, the themes identified in the interviews were overlayed with the physiological data.

3. Results and Discussion

Despite the challenges of conducting mixed-methods research [21,26,27], bringing the physiological data and qualitative data relating to the sport culture and environment (socio-psychological) together proved to be highly effective in providing a contextual understanding of physiological evidence, as well as in shedding new light on issues being experienced by the athletes but are not yet presented in physiological research on LEA. This paper provides valuable real-world information that may not otherwise be demonstrated in these small yet unique cohorts of elite female athletes if the research was completed in their respective research domains. Burden et al. [28] mentions that research involving elite female athletes is often ‘statistically underpowered’ and therefore unlikely to be published. The current paper has evidence to support Burden and colleagues; however, what this paper adds is a greater understanding of the sporting environment, the relationships amongst athletes and coaches, as well as the influence of the sporting culture in which the female athletes are immersed on a day-to-day basis. The following three examples were selected from each sport to demonstrate the socio-physiological influences on the physiological markers towards the development of LEA. A summary of the main quantitative findings is shown in Table 3.

Table 3. Overview of quantitative findings from the three sports.

<table>
<thead>
<tr>
<th>Sport</th>
<th>Summary of Findings</th>
</tr>
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| Endurance (n = 11) | 82% classified as having LEA  
Positive relationship between EI and serum ferritin levels |
| Rugby (n = 9)       | 22% classified as having LEA  
Those classified as having LEA had higher EEE levels than those classified as having HEA |
| Cycling (n = 11)    | 70% classified as having LEA  
Those classified as having LEA had lower EI and lower fat intake than those classified as having HEA |

LEA, low energy availability; HEA, higher energy availability; EI, energy intake; EEE, exercise energy expenditure.

3.1. Endurance Example: Monitoring Food Intake to Keep Low Body Weight and Increase Performance

The quantitative data demonstrate that 82% (n = 9) of the endurance athletes were classified as having LEA. The endurance athletes showed a positive relationship between the daily EI (relative to body mass) and serum ferritin levels \( (r = 0.610, p = 0.046) \). This result
concurs with Ackerman and colleagues [2], who found that low ferritin levels were 1.6 times more likely in female athletes at risk of LEA. Although not statistically different, the athletes with LEA had higher average EEE values compared to the athletes categorised with an EA of >30 kcal/kg FFM/day (LEA: 1268 ± 489 and HEA: 915 ± 262 kcal/day, p = 0.289; Supplementary Table S1). This suggests that athletes with an LEA are not meeting their energy intake requirements for the energy that they are expending in exercise. Furthermore, as observed in the athletes with the greatest energy deficits, these athletes also had a greater drive for abnormal eating behaviours (e.g., meal skipping, rigid routines around food and exercise, and food restriction) to increase body leanness and improve performance.

The qualitative data confirm a strong perceived association between leanness and performance: ‘Triathlon is a power to weight sport, so in my own mind I think if I’m a bit leaner, a little bit lighter, keep my strength, I’m going to be faster’ (E1). These beliefs were common among the endurance athletes and could be impacting the reduction in the energy intake, therefore suppressing the haematological measures. Previous research has shown that athletes competing in lean sports, such as endurance and triathlon training, are at a higher risk for disordered eating [29]. The endurance athletes in the current study described strict nutritional practices, which were expressed by other athletes within their community: ‘I sat eating an Anzac biscuit and one of the girls [said] “eating a biscuit? I’ll tell [coach]”. If anything that stuck in my mind from the training camp, she [was] saying “you shouldn’t be doing that”’ (E2). The interviews revealed that the drive for continued abnormal eating behaviours was being exacerbated by comments from others: ‘it becomes a positive thing to get told that you’re thin, because you associate it with running faster’ (E3).

To summarise, this cohort demonstrated that although the athletes themselves hold the belief that ‘leaner is faster’, the comments from others are what continue to drive and motivate the practice of abnormal eating behaviours, such as highly restrictive dieting practices, to maintain a lean figure. With these insights into the cultural values within endurance running and triathlon training, we can better understand how the high rates of LEA (as evidenced in the physiological data) have occurred.

3.2. Rugby Example: Hierarchy among Players and Food Surveillance

The quantitative data demonstrate that 22% (n = 2) of the rugby players were classified as having an LEA. The athletes categorised as having an LEA had a higher EEE and lower fat intake compared to the athletes categorised as having an HEA (597 ± 27, 255 ± 134 kcal, p = 0.001; 70 ± 6, 98 ± 22 g/day, p = 0.003, respectively). No other physiological differences were observed. There were no qualitative themes that focussed on increased training or reductions in fat intake that would help to explain these findings.

When the data were divided by the level of player experience (experienced vs. novice), no quantitative differences were observed (Supplementary Table S2). The qualitative data present a different picture, highlighting a strong hierarchy between the experienced players who felt they had the responsibility to guide the novice players. The experienced players asserted their dominance over the novice players by holding the novice players accountable for their nutritional practices, as explained by longstanding team members: ‘some of us [experienced players] do look out and we may take note of if one of the girls who aren’t as fit and she’s eating junk food every night’ (R2), and ‘[we]...will speak up if we [experienced players] realize [the novice players] need to start eating a lot better’ (R3). Furthermore, the experienced players openly controlled others’ food intake by making comments about others’ meals. For example: ‘If there’s something that we don’t agree with on their plate...and someone has a hash brown, we’re like “no, go put that back!”’ (R4). In addition, there was a performance standard set by the experienced players for what any player could eat. For example, a conversation from an experienced player, as shared by a novice player, was as follows: ‘...if you can run [this time] in your Bronco [fitness test], I’m fine with whatever you eat’ (R1). Furthermore, the experienced players held others accountable when the performance standards deteriorated: ‘I know that when it comes to on the field you can still perform, but if someone’s drinking, eating Macca’s [McDonald’s]...and they’re getting terrible results and they’re
not playing good, I have a problem with that’ (R6). While the experienced members were doing what they felt was best for the team in guiding and mentoring the novice players, the less experienced members internalised the culture of surveillance and expressed some discomfort in the comments being made by the experienced players about their bodies, performances, and nutritional practices. Simultaneously, the novice players also looked up to and respected the experienced players, and strove to be as fit, lean, and strong as them: ‘they’re so ripped, I want to be like them’ (R7).

Here, we highlight from the qualitative data the clear hierarchy amongst the team (based on seniority) and the food surveillance behaviours driven by the more experienced members. The experienced players saw their positions as ‘encouraging [the younger players] and showing them what’s good [to eat]...to teach them’ (R4), and the novice players confirmed that the experienced players were ‘guiding’ them, for example, ‘...don’t go buy that, we don’t go [to] that [dessert] table’ (R1). We noted that the hierarchy imposed by the experienced players had a behavioural influence on the novice players. To add, the hierarchy permeated to other aspects of life, not just in rugby situations, as a novice player shared: ‘one of the girls didn’t want to drink and have much cake [at a function] because the senior girls were there’ (R5).

The hierarchical dynamics within a sporting team and the culture surrounding team meals meant that nutritional behaviours were being controlled and monitored. This is one avenue where novice players may be at risk of developing LEA-related symptoms in a team culture where the pressure to conform (and perform) is being enhanced by the expectations of the more experienced players, despite the physiological data appearing to be ‘normal’.

3.3. Cycling Example: Coach–Athlete Relationships

We observed that 70% (n = 7) of the cyclists were categorised as having an LEA. A difference in the EI was observed between those with an LEA and those with an HEA (33.9 ± 3.2, 43.4 ± 3.4 kcal/kg BW/day, respectively, p = 0.003; Supplementary Table S3), which came from a reduction in carbohydrate and protein intake. No differences were observed in the remaining physiological measures. However, the interview data reveal interesting interactions between the athletes and those in higher power positions, such as male coaches, that can partially explain the reasons for the athletes’ reductions in EI and EA levels. The interviews highlighted a weight-conscious culture in elite track cycling that was regularly reinforced by comments from others: ‘I have seen everything...like you should be really skinny, and that came from the men...so it was [an]old-school thought process [by] the coaches’ (C2). These opinions and pressures are mirrored in the international literature that attribute coaches as key sources of pressure among 60% of elite athletes from leanness- and non-leanness-focused sports [30]. Similarly, the performance-related pressures experienced from a coach were observed in 53% of elite female athletes from New Zealand [31]. Furthermore, albeit a smaller proportion, 11% of elite New Zealand female athletes experienced being told by their coach to lose weight for performance-related reasons [31]. The comments and pressures from coaches to reduce body weight or lose fat mass may result in drastic weight loss strategies through abnormal eating behaviours, exacerbating the risk of developing LEA.

The pressures and expectations from male coaches extended outside of training sessions, particularly if the teams were travelling. An earlier experience was shared by a cyclist who was publicly embarrassed by a previous coach in front of her teammates and other staff about the food that was on her plate: ‘he’d be like “should you be eating that?”’ (C1). This athlete further reflects, ‘[this comment] just makes for such a negative culture and feels like you are being watched...like, I can’t eat that because someone is going to judge me’. Another cyclist shared a similar concern: ‘I need to go back for a helping of potatoes because I’m racing tomorrow, but what’s everyone going to think?’ (C3). As illustrated in these comments (and highlighted in athletes in endurance and rugby), the dining hall can be a vulnerable place for encouraging or developing abnormal eating behaviours. This was further exacerbated when public comments were made by those in power [30], prompting unhealthy relationships with food among a number of the athletes in this study.
A low EI level seemed to be a factor explaining LEA in the cyclists, and a higher EEE level seemed to be a factor explaining LEA in the rugby players. As mentioned, there are scenarios where cyclists could be restricting EI. However, the higher EEE observed in the rugby players was not confirmed in the qualitative data.

3.4. Strengths and Limitations

There are many strengths to this study. First, this is the first study to use a mixed-methods approach in working to realise the possibilities and challenges of LEA research. Second, the data include elite athletes from three different sports, including team and individual sports. Third, we had a high adherence to data protocols and support from the coaches and support staff associated with the athletes. Fourth, while we acknowledged that some athletes would engage in self-preservation approaches in the interviews depending on their trust and rapport with the researcher [32], the athletes were comfortable in openly sharing their experiences despite some topics being highly personal.

However, we acknowledge that there are limitations to measuring the EA, similar to most studies in the literature [33]. LEA status identification may be impacted by incorrect dietary intake or exercise energy expenditure values [33], and the pre-determined threshold of 30 kcal/kg FFM/day may not reflect the LEA threshold and severity of symptoms of an individual. The DEXA machines differed between the endurance and rugby athletes compared to the cyclists. This would have impacted the inter-sport comparisons. However, as the data were only compared within each sport, this limitation did not alter the validity of the results. Also, the statistical analysis between the groups was limited due to the unbalanced group sizes and a small number of participants. Therefore, the statistical differences were limited and did not have sufficient power to reflect meaningful differences.

3.5. Summary

To summarise, the data from this study demonstrate the value of using mixed-methods approaches for understanding the socio-psychological and physiological complexities of health conditions such as LEA. Here, we highlight that bringing the qualitative, socio-psychological data via interviews together with the findings of the quantitative physiological data can offer a more holistic understanding of the complexity of LEA. In doing so, we uncovered sport-specific examples from the athletes and a relationship in developing LEA or LEA-related symptoms. Across the three sports, the findings highlight how informal conversations with teammates and others in the sporting environment (i.e., coaches) powerfully impact athletes’ feelings about their bodies, relationships with food, and thus, the risks of developing LEA. The athletes’ shared experiences demonstrate that the sporting environment and their individual perceptions can have significant contributions to how athletes fuel their bodies for health and performance. As a result, this can have a significant impact on the energy availability and LEA risk.

By developing a mixed-methods approach, we emphasised a complex interaction between the socio-psychological data that enhance the findings of the physiological data. We demonstrated that mixed-methods approaches will be important in realising Ackerman and colleagues’ [17] call for a ‘revolution in sport culture and awareness regarding energy availability’. Such a ‘revolution’ requires an in-depth understanding of the sporting cultures that are impacting female athletes’ risks, experiences, diagnosis, and recovery from LEA. Yet, psychometric testing is not fit for the task of assessing and evaluating how sporting cultures are impacting women’s health experiences. Thus, socio-psychological methods are a valuable addition to the LEA methodological toolbox, particularly for those seeking to invest in strategies towards prevention via educating coaches and support staff about the importance of their everyday practices (i.e., comments on food and bodies) and towards body-positive interactions among athletes. Future research findings using mixed-methods approaches to understand the complexities of LEA will allow for more effective communication between athletes and staff, and athlete and staff education, towards identifying and
remedying unhealthy sporting environments that are damaging female athletes’ health and wellbeing.

4. Conclusions

This study demonstrates the value of implementing a mixed-methods approach to understand and further highlight the complexity of LEA (which can be influenced by external factors in the broader sporting environment). As illustrated through three examples, the qualitative data helped us to interpret the quantitative data, therefore enhancing the understanding of the development of LEA. For example, the interview data from the endurance athletes reveal that deep cultural associations between performance and leanness, as well as comments from others, drive restrictive eating behaviours, which can explain the higher prevalence of LEA. Furthermore, the coach–athlete relationship among cyclists has a lasting impact on the perceptions and behaviours of energy intake, particularly in team dining settings. Within rugby players, the qualitative data reveal a hierarchy amongst the team, with the experienced players monitoring the food intake behaviours of the novice players. The qualitative data provide additional understanding and insight into the development of LEA. The mixed-methods approach also shows the intricate nature of each sport, the challenges athletes face outside of training sessions (i.e., while travelling or eating together), and the scenarios where athletes are at a greater risk of developing LEA, including (1) the normalisation of restrictive dietary practices to maintain a low body fat percentage; (2) experienced athletes imposing subtle dietary practices on less-experienced athletes; and (3) the influence of athlete–coach power relationships on dietary practices. Each sporting environment will be different, but future LEA research should consider how factors within the broader sporting culture (i.e., coach and athlete values and ways of talking about bodies, food, and performance) are impacting athletes’ risks of developing LEA, and their experiences of recovery.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/physiologia3030033/s1, Table S1: Energy availability, macronutrients, bone measures, haematology and metabolic rate comparison between endurance athletes with low energy availability (LEA) and higher energy availability (HEA); Table S2: Energy availability, macronutrients, bone measures, haematology and metabolic rate comparison between experienced and novice rugby players; Table S3: Energy availability, macronutrients, bone measures, haematology and metabolic rate comparison between cyclists with low energy availability (LEA) and higher energy availability (HEA).

Author Contributions: Conceptualisation, K.L.S., H.T. and S.T.S.; formal analysis, K.L.S., H.T. and S.T.S.; funding acquisition, H.T.; investigation, K.L.S., H.T. and S.T.S.; methodology, K.L.S., H.T. and S.T.S.; supervision, H.T. and S.T.S.; writing—original draft, K.L.S.; writing—review and editing, K.L.S., H.T. and S.T.S. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: This study was conducted in accordance with the University of Waikato Human Research Ethics Committee (HREC(Health)#2017-13/24/51).

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

Data Availability Statement: Data are available by contacting the corresponding authors.

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