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Energy Availability and Body Composition in Elite Athletes: Two Sides of the Same Coin

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Abstract: Background/Objectives: Energy availability (EA) is essential for maintaining physiological functions, significantly influencing athletes' health and performance. Nutritional behaviours, however, vary across sports. This study aims to assess EA levels in athletes from different disciplines, focusing on the relationship between EA and body composition in endurance athletes compared to rugby players. **Methods:** The study involved 18 endurance athletes (15 men, 3 women) and 36 rugby players (all men). Data were gathered through interviews, questionnaires, and bioimpedance analysis. Energy intake (EI) was measured with a 24-hour dietary recall, and exercise energy expenditure (EEE) was calculated using the IPAQ questionnaire. EA was calculated as EA = (EI − EEE) / fat-free mass (FFM), with results categorized into clinical, subclinical, and optimal ranges. **Results:** The endurance group had a lower average FFM (57.81 kg) compared to the rugby players (67.61 kg). EA was also significantly lower in endurance athletes (11.72 kcal/kg FFM) than in rugby players (35.44 kcal/kg FFM). Endurance athletes showed more restrictive nutritional behaviour with lower EI and higher EEE, but both groups maintained body composition within normal ranges. **Conclusions:** Endurance athletes exhibit greater nutritional restrictions compared to rugby players, though their body composition remains healthy. Further research is required to investigate the long-term effects of low EA on performance, injury risk, and potential impairment when EA falls below the optimal threshold of 45 kcal/kg FFM/day.

Keywords: energy availability; energy intake; energy expenditure; body composition; rugby players; endurance athletes

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1. Introduction

Energy availability (EA) is currently of interest in sports medicine, particularly due to the complex management required to balance caloric intake with the energy expended during training [1]. A discrepancy has been described among competitive athletes, characterized by low EA levels, which can have potential health and sports-related consequences, such as reduced performance and increased risk of injury [2]. This aspect has not been largely evaluated, despite the current literature, suggest that some athletes, who need to maintain a constant performance for long periods, are more exposed to the risk of low EA. This issue seems to be associated with poor knowledge in this field [3] among athletes who tend to consider a low Body Mass Index (BMI) as a key component for optimal performance. It is, in fact, common to limit daily caloric intake, especially by reducing carbohydrates, thereby increasing the risk of developing a state of low EA. In addition to limiting caloric intake, these sports involve very high training volumes, which further widen the gap between energy intake and calories burned through sports activity. This behaviour is often associated with a kind of dependence on maintaining this incorrect approach [4]. On the other hand, in mixed sports, particularly team sports that involve a lower endurance component but require greater physical strength, a low EA seems to be less prevalent. Current literature does not report a specific trend among different types of sports. Therefore, the objective of this study is to assess EA levels and body composition in athletes practicing at least two different sports disciplines and high energy demand, to evaluate any

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differences in the incidence of low energy availability or increased risk of developing it, based on the varying athletic demands of the sport practiced.

2. Materials and Methods

Population Studied:

The study was conducted with two groups of athletes. The first group (18 subjects, including 15 men and 3 women) consisted of endurance athletes practicing disciplines such as long-distance running, cycling, and swimming. They had an average age of 47.61 ± 11.37 years, a weight of 74.47 ± 8.75 kg, and a height of 175.78 ± 8.57 cm. Their BMI was within the normal range at 23.92 ± 1.67 kg/m². The second group comprised a team of athletes, including 36 male rugby players, with an average weight of 86.50 ± 7.07 kg, an average height of 181.83 ± 5.66 cm, and an average BMI of 26.15 ± 1.62 kg/m². The athletes were engaged in regular training as normally followed in the seasonal time. The endurance athletes (E) trained for almost 3 hours per session, at least 3-4 days a week, with swimmers training every day for at least 2 hours. The rugby players (R) trained for at least 3 hours, 3 times a week, and played a game on the weekend. Each participant provided written informed consent for data processing and participation in the evaluation. However, since they were regularly monitored at the Sports Medicine Centre of the University of Florence, approval from an ethics committee was not necessary. Data are available on the Sports Medicine website on behalf of the corresponding author.

Methods:

The LEAF-Q (Low Energy Availability in Females Questionnaire), which is validated for women, has been used, but some studies have adapted it for men. [5], moreover were used height and weight measurement and bioelectrical impedance analysis.

Face to Face Interview

During the interview, a 24-hour recall was conducted to evaluate the participants' Energy Intake (EI). Each subject was asked to detail all meals consumed the previous day, including snacks, condiments, supplements, food brands, and an estimate of habitual water consumption. Athletes were also asked to provide as precise an indication of food portion sizes as possible. When they were unsure of the weights, a food atlas was used to identify the quantity consumed for each food. After obtaining a detailed description of the daily food intake, the total daily calories were calculated to determine the energy intake (EI) of each athlete.

During the face-to-face interview, athletes were also asked to describe in detail the types and duration of their workouts, providing information on the volume and intensity of the sessions. To find the average daily training time, the total weekly training hours were divided by seven.

IPAQ Questionnaire

To assess exercise energy expenditure (EEE), the IPAQ questionnaire was administered **[6–8]**. This questionnaire provides a result in METs (metabolic equivalents) consumed per minute based on the previous week's workouts. This value was then converted into METs consumed per hour per training day by dividing by 60 and then by the total weekly training hours.

Once these data were obtained, EEE was calculated. METs are expressed in $\frac{\mathbf{Kcal}}{\mathbf{h*weight}}$ so using the formula $\boldsymbol{Kcal} = \boldsymbol{MET} * \boldsymbol{h} * \boldsymbol{weight}$, where METs are those obtained from the IPAQ converted into hours, h represents the daily training hours, weight is the athlete's weight, the EEE of each participant was calculated **[6,9]**.

The bioelectrical impedance analysis provided data on body composition and hydration status. Detailed aspects such as FFM (fat-free mass), which is of interest for calculating athletes' energy availability using the formula $\boldsymbol{EA} = \frac{\boldsymbol{EI-EEE}}{\boldsymbol{FFM}}$, ASMM (appendicular skeletal muscle mass) using the Janssen formula, FM (fat mass), and phase angles were assessed **[10,11]**.

Energy availability was determined using the following value ranges: clinical state if <30 kcal/kg FFM for both sexes, subclinical state for values of 30-40 kcal/kg FFM for men or 30-45 kcal/kg FFM for women, and optimal state for values ≥40 kcal/kg FFM for men and ≥45 kcal/kg FFM for women.

Body Composition Analysis

Bioimpedance analysis was selected to assess body composition. The bioelectrical parameters of resistance (R) and reactance (Xc) were obtained using a BIA 101 Anniversary Sport Edition analyzer (Akern Srl, Florence, Italy), which generates an alternating sinusoidal current of 400 mA at 50 kHz (±0.1%). Prior to each assessment, this instrument was calibrated with a known impedance circuit supplied by the manufacturer.

The measurements were performed following the guidelines, with arms and legs slightly apart to prevent contact with the body. The readings were taken after a 5-minute stabilization period, during which the participants remained still to ensure a uniform distribution of body fluids. The injector electrodes were placed on the dorsal surface of the right hand (near the third metacarpophalangeal joint) and right foot (near the third metatarsophalangeal joint). The sensing electrodes were positioned approximately 5 cm away from the injector to avoid interaction between the electric fields and to prevent overestimation of the impedance values.

Impedance (Z) was determined as (R2 + Xc2)1/2, and phase angle (PhA) as tan−1 (Xc/R · 180°/π). R, Xc, and Z were adjusted for height (R/H, Xc/H, Z/H). According to conventional BIVA, Z/H is inversely related to total body water (TBW) [12]. Conversely, vector direction indicates cellular health and cell membrane integrity and is inversely related to the extracellular/intracellular water (ECW/ICW) ratio [13]. All interpretations should consider both Z/H and PhA in combination with the vector position on the Resistance-Reactance (RXc) graph [14]. On this graph, shifts in vectors parallel to the major ellipse axis reflect differences in tissue hydration (a longer vector indicates less fluid, while a shorter vector suggests more body fluids). Shifts in the vector parallel to the minor axis of the ellipses indicate changes in cell mass and the ECW/ICW ratio (a shift to the left suggests an increase in cell mass and a reduction in the ECW/ICW ratio, while a shift to the right indicates a decrease in cell mass and an increase in the ECW/ICW ratio [15]).

Statistical Analysis

All data were expressed as mean ±SD and compared by T-Student Test for paired data. The significance of the differences between the results of the two groups of athletes was evaluated using a two-tailed t-test was pointed at $p<0.05$.

3. Results

The body composition was assessed by BIVA (Bioeletrical vector analisys) The values of fat-free mass (FFM), skeletal muscle mass (SMM) estimated by the Janssen formula, and fat mass(FM) were measured for both groups of athletes.

E athletes had an average Fat-Free Mass (FFM) of 57.81 ± 7.62 kg, while R players had a higher average of 67.61 ± 5.01 kg.
The percentage of Appendicular Skeletal Muscle Mass (ASMM) was similar between the two groups: the first group had an average of 30.01 ± 6.38 kg, and the second group had an average of 27.26 ± 4.70 kg.

In E athletes the FM value was of 22.07 ± 4.77%, and rugby players of 21.66 ± 4.34%, not different. The FFM values resulted on the contrary significantly different between the two groups o, despite similar for ASMM (Janssen) as reported in Table 1. The average phase angles for the two groups were respectively 6.37 ± 0.54 for E athletes and 7.13 ± 0.40 for R players. The difference between these values was statistically significant , despite within the normal range . From the IPAQ questionnaire, the E athletes showed an EE of 6460 ± 1565.41 MET, while R players had 4152.14 ± 2447.35 MET. The training level was for E athletes between 10 and 14 hours per week, with an average of 12.39 ± 1.50 hours per week, equivalent to 1.77 ± 0.21 hours of daily training. The R players, on the other hand,

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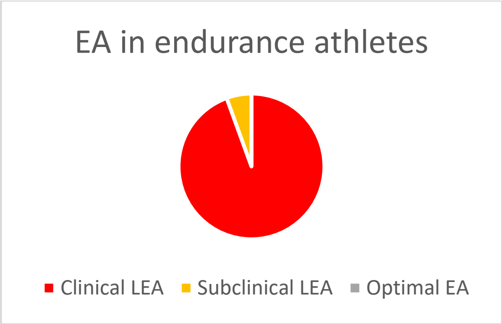
reported to train at least three times a week, totalling about 7 hours per week, equivalent to an average of 1 hour of daily training.

Table 1. Nutritional and anthropometrics parameters of E and R athletes. Legend: EI: Energy Intake; EEE: Energy Expenditure; EA: Energy Availability; FM: Fat Mass; FFM: Free Fat Mass, ASMM: Appendicular Skeletal Muscle Mass.

	Endurance athletes	**Rugby athletes**	**p**
EI	1796.89 +/- 405.46	3237.28 +/- 158.80	p < 0.01
EEE	1144.41 +/- 311.32	839.52 +/- 463.78	p = 0.01
EA	11.72 +/- 9.05	35.44 +/- 6.63	p < 0.01
Basal Metabolism	1681.77 +/- 147.42	1904.28 +/- 93.41	p < 0.01
FM	22.07 +/- 4.77	21.66 +/- 4.34	p < 0.01
FFM	57.81 +/- 7.62	67.61 +/- 5.01	p < 0.01
ASMM	30.01 +/- 6.38	27.26 +/- 4.70	p > 0.05
Phase Angle	6.37 +/- 0.54	7.13 +/- 0.40	p < 0.01

Based on the data and face-to-face interviews with the athletes, the EI, EEE, and EA values for each athlete were calculated. For the E group, the EI was on average 1796.89 ± 405.46 kcal per day, the EEE was 1144.41 ± 311.32 kcal per daily training session, and the EA was 11.72 ± 9.05 kcal/kg FFM. Rugby players (R) had an average EI of 3237.28 ± 158.80 kcal per day, an average EEE of 839.52 ± 463.78 kcal per daily training session, and an average EA of 35.44 ± 6.63 kcal/kg FFM. (Table1).

Examining the data for each athlete, 17 endurance athletes were in a clinical state of energy availability, and one athlete was in a subclinical state. No athlete in the first group had an optimal energy availability level. As for the rugby players, 7 were in a clinical state of energy availability, 22 were in a subclinical state, and 7 were in an optimal state. The global EA of the two groups of athletes classified as clinical, suboptimal and optimal are summarized in the Figure 1 (A-B). EI, EEE, and EA levels in the two groups of athletes are showed in the Figure 2.



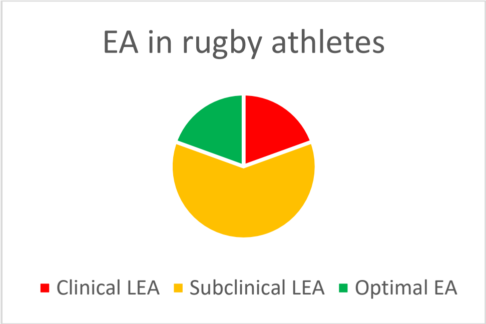


Figure 1. (A left; B right): representing the EA levels in endurance athletes (E) and in rugby players (R), respectively. *Caption:* In E athletes, no optimal EA was observed, while in R players, the majority were within the subclinical and optimal range.

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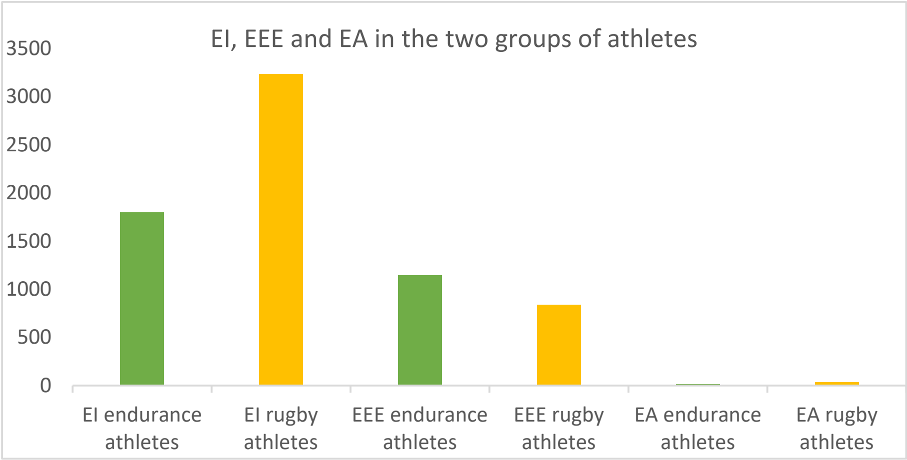

Figure 2. Comparison of average EI, EEE, and EA levels in the two groups of athletes.

4. Discussion

The data collection and analysis reveal that the athletes in the two groups had different physical characteristics based on the type of sport practiced. Endurance athletes had a lower weight compared to rugby players but had a similar amount of skeletal muscle mass and fat mass relative to their body weights. This is also evident when analysing the average BMI values of the two groups, which were significantly higher for the rugby players than for the endurance athletes. These physical characteristics reflect the type of sport practiced; rugby players had higher body masses compared to endurance athletes.

Endurance athletes had a very high training volume, reaching up to 14 hours per week. Despite the significant physical effort required, the caloric intake from their diet was particularly low, sometimes as low as 1221 calories per day. The caloric intake was sufficient, for most athletes, only to sustain their basal metabolic rate. During interviews, the athletes often mentioned that nutritionists or professionals in the field did not follow them and that the choice to limit their caloric intake was voluntary, especially regarding carbohydrates. They believed that maintaining a low body weight would ensure performance regardless of the competitive preparation period. This significant gap between caloric intake and the energy expended during training results in very low available energy for the normal performance of all physiological functions. All athletes in this group were in a clinical state of low energy availability, with values significantly below the clinical threshold. Only one athlete fell into the subclinical range, and none was in the optimal range.

For the rugby athletes, the situation was significantly different. The training volume for this group was much lower compared to the endurance athletes, totalling about 7 hours of training per week. Consequently, the caloric expenditure from exercise was lower. This was associated with a much richer diet compared to the endurance athletes. Rugby players, needing to maintain a higher body mass and an important strength component to be competitive, had to maintain a higher caloric intake, with almost none reporting a dietary energy intake below 3000 calories per day. As a result, their energy availability values were significantly higher. Only 7 athletes were in a clinical state of energy availability, 22 were in a subclinical condition, and 7 were in an optimal state.

Comparing the results obtained between the two groups of athletes, those practicing endurance sports had a significantly higher incidence of low energy availability; 94% of them were in a clinical condition. In contrast, only 19% of rugby athletes were in a state of clinical low energy availability. Athletes in both groups had phase angles within the normal range, indicating good hydration status and healthy cell membrane structure.

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5. Conclusions

According to current literature and the data obtained, endurance sports appear to be more prone to issues of low energy availability compared to mixed sports such as rugby. Despite all the athletes investigated engaging in high-intensity training, rugby players need to maintain a higher-than-average body weight. Endurance athletes, who are dedicated to long-term sports activities, often consciously limit their energy intake, sometimes engaging in disordered eating behaviours. They may consume a caloric amount suitable for a sedentary person in an attempt to appear leaner, weigh less, and gain a perceived advantage in long-distance races. This can have significant health consequences, as the body may not have sufficient energy to maintain essential physiological functions, leading to the suppression of some functions to preserve others. Over time, this dysregulation of energy balance could negatively affect health, including cardiac function, recovery from training, athletic performance, and increase the risk of injuries. Regarding rugby, a mixed team sport that includes endurance, strength, and muscle explosiveness components, it is not exempt from low energy availability issues, but it is less impactful compared to pure endurance sports. In this type of athlete, there seems to be greater awareness of the importance of dietary intake, driven by the need to maintain a physique and strength to remain competitive against players from other teams.

The study concludes by highlighting the importance for athletes, especially those practicing endurance activities, to be followed by a nutritionist or a professional in the field of nutrition and to be sensitized to the relevance of nutrition in sports. Managing this aspect autonomously, due to ignorance or false personal beliefs, risks significantly compromising their health. Relying on external support for dietary management will allow athletes to adjust their caloric and nutrient needs according to the volume and intensity of training, ensuring better recovery, maximizing performance, and improving or maintaining their health. Additionally, greater awareness among athletes about the role of nutrition will reduce the risk of developing disordered eating behaviours or actual eating disorders.

6. Limitations and Future Perspectives

The main limitation of this study concerns the determination of the athletes' energy intakes. These were calculated using the 24-hour recall method, which evaluates the subject's diet over a very short period. Additionally, there may be a recall bias, where participants may not remember to mention some foods consumed, leading to an underestimation of the calories consumed.

A second limitation of this type of study lies in the lack of agreement in the scientific community on the method for quantifying values to calculate energy availability. Consequently, results can vary from study to study depending on the methodologies and tools used to identify energy intakes and calories burned through training. Identifying a validated method to calculate energy availability will, over time, allow for easier and more precise comparisons of results and conclusions from studies on this topic, increasing the possibilities of mitigating the problem and the consequences of low energy availability in sports.

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Data Availability Statement: Data are available on behalf of Prof. L Stefani.

Conflicts of Interest: The authors declare no conflicts of interest.

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