

# Are athletes adequately fuelled and informed? Dietary intake, energy availability and nutrition knowledge across athletes and their coaches

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## Research Article

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# Abstract

## Purpose

To assess the adequacy of dietary intake and the prevalence of low energy availability in athletes, while investigating the nutrition knowledge of athletes and their coaches.

## Methods

Nutrition knowledge was assessed using the Nutrition Knowledge Questionnaire for Young and Adult Athletes (NUKYA), dietary intake was assessed using a 7-day food diary.

## Results

184 athletes and 13 coaches agreed to participate in the study. Overall nutrition knowledge was moderate (mean score: 46.5 points), where coaches scored significantly higher than athletes ( $p < 0.05$ ). Mean energy availability was 24.8 kcal/kg Fat-Free Mass (FFM)/day, and 68.5% of athletes were classified in a Low Energy Availability (LEA) threshold. Compliance with carbohydrate recommendations was low (9.8%), while protein (48.9%) and fat (59.2%) compliance were moderate. High rates of micronutrient inadequacy were observed, particularly for vitamin D (77.2%), vitamin E (73.4%), calcium (60.9%), and folate (56.0%). Coaches' nutrition knowledge was positively associated with athletes' energy ( $r = 0.168$ ,  $p = 0.022$ ) and carbohydrate intake ( $r = 0.199$ ,  $p = 0.007$ ), whereas athletes' own nutrition knowledge was not associated with dietary intake.

## Conclusion

Despite moderate knowledge, athletes exhibit a high prevalence of LEA and inadequate carbohydrate intake. The findings underscore the critical role of coaches as mediators of nutritional behaviour and the necessity of implementing specialized nutrition education programs led by registered dietitians to optimize athlete health and performance.

## 1. Introduction

Adequate nutrition is a cornerstone of optimal athletic performance, supporting energy demands, recovery, and long-term health. The dietary requirements of athletes differ substantially from those of the general population, as they must account for increased energy expenditure and macronutrient periodization to optimize training adaptations and competition outcomes [1]. Moreover, it is essential to implement the most appropriate dietary strategies to prevent nutritional deficiencies [2] such as low energy availability (LEA) and relative energy deficiency in sport (REDs) [3, 4]. As these requirements are

influenced by body composition, type of sport, and environmental factors, the diet must therefore be individually tailored for each athlete by a registered dietitian specialising in sports nutrition [1, 5].

There are extrinsic determinants that may positively or negatively influence food intake, including environmental determinants such as culture, time, economic conditions, family, and religion [2, 6–8]; individual determinants such as habits, skills, attitudes, tastes, preferences, and, in particular, nutrition knowledge [6, 7, 9, 10]; and additional training-related determinants such as high training volumes, attempts to improve performance parameters associated with body weight, efforts to modify body composition, and aesthetic considerations [4].

Nutrition knowledge is commonly defined as the understanding of concepts and processes related to nutrition and health, including knowledge of diet and health, diet and disease, major sources of nutrients, dietary guidelines, and recommendations [11, 12] plays a critical role in shaping the behaviours [13], particularly regard to food choices, estimation of energy requirements [14], and diet intake [15], in addition to being an important component for health [16] and in the establishment of eating habits [9, 17]. Athletes who are better informed about their nutritional requirements are more likely to meet energy needs, consume adequate macronutrients, and avoid maladaptive behaviours such as unnecessary restriction or excessive supplementation [18].

Despite its importance, evidence consistently suggests that athletes' nutrition knowledge is often moderate to inadequate across a variety of sports and competitive levels. Systematic reviews [18, 19] and cross-sectional studies [9, 20–22] report significant gaps in athletes' understanding of recommended dietary guidelines, nutrient intake, and the role of supplements, with many athletes scoring low to average on validated nutrition knowledge questionnaires. For example, elite athletes have been found to have nutrition knowledge scores similar to non-athletes and much lower than nutrition professionals, and even female athletes often demonstrate only average knowledge [9, 21].

Even though athletes may understand basic concepts (e.g., importance of hydration or carbohydrates), their knowledge of sport-specific dietary recommendations [8, 10, 16, 23], such as carbohydrates loading strategies [24] or energy periodization [7] is frequently limited placing them at a higher risk for LEA. LEA is defined as insufficient dietary energy intake to support physiological function after accounting for exercise energy expenditure and is associated with adverse health and performance outcomes [4].

Sex-based differences in nutrition knowledge have been inconsistently reported, but several studies [25–27] indicate that female athletes often achieve higher scores on nutrition knowledge questionnaires compared with males. However, women may also be at greater risk for LEA due to restrictive dietary practices, weight-sensitive sports, and menstrual cycle-related energy fluctuations [28] regardless of nutrition knowledge [29]. Similarly, differences according to competitive level have been observed, with elite athletes tending to display higher knowledge than recreational or youth athletes, likely due to increased access to professional support and education programs [30, 31].

Nonetheless, the relationship between knowledge and behaviour is not always linear: some highly knowledgeable athletes still engage in suboptimal dietary practices due to convenience, taste preferences, financial limitations, or external pressures such as making weight categories [32]. As demonstrated by Pai et al. [29] where women who scored higher in the nutrition knowledge questionnaire had a greater risk of LEA.

Coaches represent another crucial factor influencing athletes' nutritional behaviours. In many team and individual sports, athletes frequently turn to coaches for guidance on diet, hydration, and supplementation [14, 33, 34] but they may lack knowledge about sports nutrition [35]. However, some studies [26, 36, 37] consistently show that many coaches possess insufficient nutrition knowledge, with most scoring below the threshold considered adequate for providing sound dietary advice to athletes. Despite this, a significant proportion of coaches still offer nutrition guidance to their athletes, often relying on outdated, anecdotal, or non-evidence-based sources such as the internet or their own former coaches [36–38].

Therefore, the present study aimed to investigate the nutrition knowledge of athletes and their coaches, as well as the dietary intake of athletes, to determine whether it conforms to current recommendations.

## 2. Methods

### 2.1. Type of study, study design and participants inclusion and exclusion criterium

This study was designed as a cross-sectional observational study aimed at evaluating nutritional knowledge, dietary intake, and low energy availability (LEA) in athletes.

The primary objectives were:

- 1) To evaluate the nutritional knowledge of athletes and their coaches and its potential impact on athletes.
- 2) To assess dietary intake of athletes to see if it meets nutritional recommendations.
- 3) To analyse the relationship between athletes' nutritional knowledge, dietary intake, and energy availability.
- 4) To explore whether these variables differ according to the athlete's competitive level and between sexes.

Participants were recruited from local and national sports clubs and national federations, with the assistance of coaches and team managers to ensure eligibility using a non-probabilistic recruitment method.

Participants were included if they were between 16 and 35 years old, had been actively engaged in competitive sports for at least two consecutive years with a valid sports federation license, trained three

or more times per week, and met the criteria to at least be tier 2 (Regional level) of sport classification framework [39] and were in the competition period of the season defined as a period of training in which competition performance is stabilized as much as possible so that an athlete can produce optimal performance in key competition [40]. Athletes were excluded if they had medical conditions affecting metabolism, hormonal status, or dietary intake, current injuries or rehabilitation limiting training or altering dietary patterns, use of medications in the previous three months, pregnancy or lactation.

The inclusion criteria for the coaches were only that at the time of data collection they were the coach of that group of athletes. Failure to meet this criterion resulted in exclusion from participation in the study as a coach.

The sports participants were classified according to the competitive level proposed by McKay et al. [39] as follows: regional level (tier 2), national level (tier 3), and the elite level (tier 4) and world class (tier 5) were grouped together as international level.

## **2.2. Dietary intake, physical activity, and energy availability assessment**

To evaluate the energy intake (EI) of athletes, a food diary was completed by the athletes themselves over a seven-day period. This was done using a template that was provided to them after they had completed the nutrition questionnaire. The templates included instructions on how to complete them and provided guidance for athletes who had any queries.

The data obtained from the seven-day food diary was processed using the DietoPro nutrition software (Port de Sagunt, Valencia, Spain, <https://dietopro.com/>) to calculate the total energy and nutrient intake. DietoPro is a software program that consolidates national and international food databases to construct a comprehensive food database and evaluate dietary intake patterns [41].

Nutrient intake was compared with the American College of Sports Medicine (ACSM), the Academy of Nutrition and Dietetics (AND), and the Dietitians of Canada (DC) guidelines [1] which recommends that athletes consume 1.2 to 2.0 g/kg bodyweight per day (g/kg BW/day) of protein. Regarding fat intake, the ACSM/AND/DC guidelines [1] recommend adherence to public health directives. Consequently, this study adopted the Spanish Agency for Food Safety and Nutrition (AESAN) [42], which recommend a range of 20 to 35 % of the total energy intake should be derived from fat for the age group corresponding to the athletes recruited. Finally, for carbohydrates intake, the ACSM/AND/DC guidelines [1] recommended adjusting consumption according to the duration and intensity of training. Given that the athletes trained for a minimum of 1,5 to a maximum of 2,5 hours per day, the recommended intake of 6 to 10 g/kgBW/day was applied.

For micronutrient intake, the recommendations of AESAN [42] were applied according to the age of each participant for vitamin B1, vitamin B2, vitamin B3, vitamin B6, vitamin B9, vitamin B12, vitamin C, vitamin D, vitamin E, calcium, iron, zinc, and magnesium (Table S1), as these are considered the most relevant for athletes [1, 43].

Energy availability (EA) was calculated using the formula:  $EA = (EI - EEE) / FFM$  [4]. Where EI is the daily energy intake (kcal/day), EEE is the exercise energy expenditure (kcal/day), and FFM is fat-free mass (kg). EA represents the amount of energy available for physiological functions after accounting for the energy expended during exercise and it is presented as kilocalories per kilogram of fat-free mass (kcal/kg FFM) [4].

The EA cut-off points are as follows: 45 kcal/kg FFM for optimal, 30 to 45 kcal/kg FFM for sub-clinical EA, and < 30 kcal/kg FFM for LEA [32].

EEE was assessed using a seven-day training record, which was completed within the same diary provided for reporting dietary intake. EEE was estimated using bodyweight together with the duration and intensity of each training session, applying metabolic equivalents from the 2024 Compendium of Physical Activities [44].

FFM of each athlete was determined by subtracting fat mass from total body weight obtained via bioimpedance analysis. To do this participants were required to meet the following conditions for bioelectrical impedance measurements [45]:

- 1) Be in an overnight fast or have refrained from consuming food and beverages for at least four hours prior to measurement.
- 2) Abstain from alcohol consumption for 48 hours prior to measurement.
- 3) Avoid strenuous exercise in the 24 hours preceding measurement.
- 4) For female participants, not be menstruating.
- 5) Not have any metallic objects on the body.
- 6) Have emptied the bladder before the measurement.

Bioimpedance analysis was used Omron BF511 (Healthcare Co, Kyoto, Japan) as it shows strong correlations for body fat percentage [46, 47] and it is a cost-effective and easily transportable method [48] as measurements were conducted at the sports facilities of each club on the day following a rest day.

### **2.3. Nutrition knowledge assessment**

The Nutrition Knowledge Questionnaire for Young and Adult Athletes (NUKYA) is a reliable instrument for assessing nutrition knowledge of athletes and their coaches. It is a self-administered questionnaire comprising of 20 questions that include a total of 59 items grouped in 4 sections: macronutrients, micronutrients, hydration, and periodization. Scores were calculated by assigning +1 point for each correct answer, -1 point for each incorrect answer, and 0 points for unanswered items and were classified into one of five categories, based on the level of nutrition knowledge demonstrated: very low (0

to 20 points), low (20 to 40 points), medium (40 to 60 points), high (60 to 80 points), and very high (80 to 100 points) [9, 49].

**2.4. Statistical analysis**

Statistics were performed using the Statistical Package for the Social Sciences v.29.0 (IBM Corporation, Pittsburgh, PA, USA) and graphs were created with GraphPad Prism software v.8 (GraphPad Software, San Diego, CA, USA). Descriptive statistics were presented using the mean and standard deviation (SD) for normally distributed variables or as median (first quartile-third quartile) for non-normally distributed variables, and qualitative data were presented as percentages. Data normality was assessed with the Kolmogorov-Smirnov test. Two-group comparisons were performed using Student’s t-test or alternatively, Mann-Whitney’s Test and effect size (ES) were calculated using Cohen’s d, with the following thresholds: <0.20 indicating trivial ES, 0.20-0.49 small, 0.50-0.79 moderate, and ≥0.80 indicating large ES [50]. Competitive levels were compared using one-way analysis of variance or alternatively, Kruskal-Wallis, also calculating ES with eta-squared ( $\eta^2$ ) with  $\eta^2 < 0.01$  indicating a trivial ES, 0.01-0.06 small ES, 0.06-0.14 a moderate ES, and  $\eta^2 \geq 0.014$  a large ES [50]. Frequencies were compared using the chi-square test, calculating in addition the odds ratio (OR) and 95 % confidence interval (95% CI). Relationship between variables were assessed using the Pearson Correlation coefficient (r) distribution correlation values were 0.00 to 0.30 (0.00 to -0.30) for negligible correlation, 0.30 to 0.50 (-0.30 to -0.50) for low positive (negative) correlation, 0.50 to 0.70 (-0.50 to -0.70) for moderate positive (negative) correlation, 0.70 to 0.90 (-0.70 to -0.90) high positive (negative) correlation, and 0.90 to 1.00 (-0.90 to -1.00) very high positive (negative) correlation [51]. For the analyses, the confidence level was set at 95%.

**3. Results**

**3.1. Participants characteristics**

A total of 197 participants were included in the study, comprising 184 athletes (84 females and 100 males) and 13 coaches. Participants encompassed athletes from various competitive levels (regional to international) from both team and individual sports, detailed data are provided in Table 1. Coaches were predominantly males (69.2 % males and 30.8 % females), with an average coaching experience of 13.5 (3.6) years.

**Table 1.** Descriptive characteristics of the athletes.

| Characteristics                     | All athletes<br>(n = 184) | Female athletes<br>(n = 84) | Male athletes<br>(n = 100) | p       | ES    |
|-------------------------------------|---------------------------|-----------------------------|----------------------------|---------|-------|
| Demographics and anthropometric     |                           |                             |                            |         |       |
| Age, y                              | 19 (17.2-23.9)            | 20.1 (17.4-24.6)            | 19.5 (17.1-28.3)           | 0.356   | 0.145 |
| Height, cm                          | 173.6 (9.9)               | 166.6 (6.6)                 | 180.4 (174.5-184.1)        | < 0.001 | 1.706 |
| Weight, kg                          | 69.9 (60.0-79.6)          | 63.6 (11.7)                 | 75.6 (13.5)                | < 0.001 | 0.950 |
| BMI, kg/m <sup>2</sup>              | 22.9 (20.6-25.0)          | 22.8 (3.6)                  | 23.4 (3.4)                 | 0.309   | 0.151 |
| Fat Mass, kg                        | 15.1 (10.8-21.6)          | 19.2 (7.3)                  | 13.0 (9.0-17.8)            | < 0.001 | 0.538 |
| Fat-Free Mass, kg                   | 51.0 (43.3-63.0)          | 44.4 (6.7)                  | 61.4 (8.6)                 | < 0.001 | 2.181 |
| Sport and competitive status, n (%) |                           |                             |                            |         |       |
| Regional                            | 66 (35.9 %)               | 33 (39.3 %)                 | 33 (33.0 %)                |         |       |
| National                            | 100 (54.3 %)              | 45 (53.6 %)                 | 55 (55.0 %)                |         |       |
| International                       | 18 (9.8 %)                | 6 (7.1 %)                   | 12 (12.0 %)                |         |       |
| Team sport                          | 125 (67.9 %)              | 63 (75.0 %)                 | 62 (62.0 %)                |         |       |
| Individual sport                    | 59 (32.1 %)               | 21 (25.0 %)                 | 38 (38.0 %)                |         |       |

Abbreviations: BMI, body mass index

### 3.2. Nutrition knowledge

The results of the NUKYA questionnaire are presented in Table 2. Overall participants (athletes and coaches) demonstrated a medium level of nutrition knowledge, with a mean total score of 46.5 (33.9-60.2) and the following distribution of scores: 9.1 % very low, 23.9 % low, 37.2 % medium, 35.4 % high, and 4.6 % very high, the coaches, athletes and athletes' sex distribution are shown in Table 2.

**Table 2.** Scores distributions of NUKYA Questionnaire.

| Characteristics               | Very low    | Low         | Medium      | High        | Very high  |
|-------------------------------|-------------|-------------|-------------|-------------|------------|
| Athletes,n (%)                | 18 (9.8 %)  | 47 (25.5 %) | 72 (39.1 %) | 44 (23.9 %) | 3 (1.6 %)  |
| Coaches,n (%)                 | 0 (0.0 %)   | 0 (0.0 %)   | 1 (7.7 %)   | 6 (46.2 %)  | 6 (46.2 %) |
| Male athletes,n (%)           | 8 (8.0 %)   | 23 (23.0 %) | 44 (44.0 %) | 23 (23.0 %) | 2 (2.0 %)  |
| Female athletes,n (%)         | 10 (11.9 %) | 24 (28.6 %) | 28 (33.3 %) | 21 (25.0 %) | 1 (1.2 %)  |
| Regional athletes, n (%)      | 12 (18.2 %) | 19 (28.8 %) | 19 (28.8 %) | 16 (24.2 %) | 0 (0.0 %)  |
| National athletes, n (%)      | 6 (6.0 %)   | 27 (27.0 %) | 43 (43.0 %) | 23 (23.0 %) | 1 (1.0 %)  |
| International athletes, n (%) | 0 (0.0 %)   | 1 (5.5 %)   | 10 (55.5 %) | 5 (27.8 %)  | 2 (11.1 %) |

The average score per section for all participants was for the macronutrients section 25.4 (15.2-30.5) points, for the micronutrients section 15.3 (10.2-20.3) points, for the hydration section 5.1 (3.4-6.8) points, and for the periodization section 3.4 (1.7-3.4) points.

Although coaches consistently obtained higher scores across all sections and the total score, significant differences were observed between coaches and athletes in the total score ( $p = 0.048$ ,  $d = 0.568$ ; Figure 1A), micronutrient section ( $p = 0.017$ ,  $d = 0.675$ ; Figure 2B), and the hydration section ( $p = 0.014$ ,  $d = 0.808$ ; Figure 2C). No significant differences were observed in the macronutrient section ( $p = 0.435$ ,  $d = 0.278$ ; Figure 2A), or the periodization section ( $p = 0.397$ ,  $d = 0.318$ ; Figure 2D).

Regarding sex differences, males obtained a significant higher score than females in the macronutrients section ( $p = 0.050$ ,  $d = 0.306$ ; Figure 2E). However, no significant differences were observed in the total score ( $p = 0.680$ ,  $d = 0.162$ ; Figure 1B), the micronutrient section ( $p = 0.731$ ,  $d = 0.560$ ; Figure 2F), the hydration section ( $p = 0.754$ ,  $d = 0.063$ ; Figure 2G), or the periodization section ( $p = 0.153$ ,  $d = 0.196$ ; Figure 2H).

The evaluation of self-perceived knowledge of nutrition revealed that 26.1 % of athletes tend to underestimate their level of nutrition knowledge, 37.0 % match their level of nutrition knowledge, and 37.0 % overestimate their level of nutrition knowledge. Among coaches, 30.8 % underestimate, 53.8 % match, and 15.4 % overestimate their level of nutrition knowledge.

Regarding performance levels, the total score differed significantly across groups (Figure 1C;  $p = 0.002$ ,  $\eta^2 = 0.067$ ). Post hoc analysis revealed that international athletes scored significantly higher than regional athletes ( $p = 0.002$ ), whereas no other pairwise comparisons reached statistical significance.

When analysing the different sections of the questionnaire, no significant differences were observed in the hydration section ( $p = 0.095$ ;  $\eta^2 = 0.027$ ). Significant differences were found in the macronutrient section ( $p = 0.006$ ;  $\eta^2 = 0.056$ ), with higher scores in the international group compared to the regional group ( $p = 0.005$ ); in the micronutrient section ( $p = 0.012$ ;  $\eta^2 = 0.048$ ), with the international group scoring higher than the national ( $p = 0.047$ ) and regional groups ( $p = 0.009$ ); and in the periodization

section ( $p = 0.023$ ;  $\eta^2 = 0.041$ ), with significant differences between the national and regional levels ( $p = 0.037$ ).

Within performance levels, 19.0% of regional athletes, 5.8% of national athletes, and 0.0% of international athletes scored very low in nutrition knowledge. Low scores were observed in 28.6% of regional, 28.2% of national, and 5.6% of international athletes. Medium scores were obtained by 27.0% of regional, 45.6% of national, and 55.6% of international athletes. High scores were recorded in 25.4% of regional, 20.4% of national, and 27.8% of international athletes. Very high scores were observed in 0.0% of regional and national athletes, and in 11.1% of international athletes.

### 3.3. Dietary intake, energy availability, and level of compliance with recommendations

#### 3.3.1. Energy intake, energy availability, macronutrient intake, and micronutrient intake by performance level

Mean daily energy intake in the total sample was 2370.5 (683.4) kcal/day and mean EA for all the athletes was 24.8 (13.6) kcal/kg FFM/day.

Males showed significantly higher intakes in daily energy intake ( $p < 0.001$ ,  $d = 0.751$ ; Figure 4A) when compared to females, but females demonstrated significantly higher EA compared with males ( $p = 0.007$ ,  $d = 0.400$ ; Figure 4B).

Regarding performance level, international athletes showed significant higher daily energy intake than regional athletes ( $p = 0.027$ ; Figure 5A), with no significant differences between national and regional athletes. However, regional athletes showed significantly higher EA values than national athletes ( $p = 0.029$ ; Figure 5B) with no differences between international group with the national and regional athletes.

With reference to the EA cut-off points [32], 8.7 % of the athletes exhibited optimal EA 22.8 % sub-clinical, and 68.5 % of the 184 athletes were classified as LEA (Table 3).

**Table 3.** Energy availability status by sex and competitive level

| EA cut-off points            | Optimal     | Sub-clinical | LEA         |
|------------------------------|-------------|--------------|-------------|
| Males,n (%)                  | 6 (6.0 %)   | 20 (20.0 %)  | 74 (74.0 %) |
| Females,n (%)                | 10 (11.9 %) | 22 (26.2 %)  | 52 (61.9 %) |
| International athletes,n (%) | 3 (16.7 %)  | 4 (22.2 %)   | 11 (61.1 %) |
| National athletes, n (%)     | 6 (6.0 %)   | 18 (18.0 %)  | 76 (76.0 %) |
| Regional athletes,n (%)      | 7 (10.6 %)  | 20 (30.3 %)  | 39 (59.1 %) |

#### 3.3.2. Macronutrient intake and compliance analysis

Mean daily carbohydrate intake was 267.5 (93.1) g/day contributing 45.3 (9.0) % of total energy intake, for protein the mean daily intake was 132.7 (47.2) g/day representing 22.5 (5.4) % of total energy intake, and for fats the mean daily intake was 84.4 (34.9) g/day contributing 31.8 (8.1) % of total energy intake.

Macronutrients normalized by body weight was for carbohydrates intake 3.9 (1.5) g/kg BW/day, for protein 1.9 (0.7) g/kg BW/day, and for fats was 1.2 (0.9-1.5) g/kg BW/day.

No significant differences were found between male and female athletes for the carbohydrate intake normalized by body weight ( $p = 0.440$ ,  $d = 0.144$ ; Figure 4D), carbohydrate intake percentage ( $p = 0.909$ ,  $d = 0.017$ ; Figure 4E), protein intake normalized by body weight ( $p = 0.276$ ,  $d = 0.162$ ; Figure 4G), protein intake percentage ( $p = 0.580$ ,  $d = 0.820$ ; Figure 4H), fat intake normalized by body weight ( $p = 0.985$ ,  $d = 0.003$ ; Figure 4J), or fat intake percentage ( $p = 0.594$ ,  $d = 0.079$ ; Figure 4K). However, males showed significantly higher intakes for daily carbohydrate intake ( $p < 0.001$ ,  $d = 0.651$ ; Figure 4C), daily protein intake ( $p < 0.001$ ,  $d = 0.687$ ; Figure 4F), and in daily fat intake ( $p = 0.007$ ,  $d = 0.497$ ; Figure 4I).

Regarding intake by performance level, no significant differences were found for daily carbohydrate intake ( $p = 0.077$ ,  $\eta^2 = 0.028$ ; Figure 5C), carbohydrate intake normalized by body weight ( $p = 0.122$ ,  $\eta^2 = 0.023$ ; Figure 5D), carbohydrate intake percentage ( $p = 0.427$ ,  $\eta^2 = 0.009$ ; Figure 5J), daily protein intake ( $p = 0.185$ ,  $\eta^2 = 0.0018$ ; Figure 5F), protein intake normalized by body weight ( $p = 0.168$ ,  $\eta^2 = 0.020$ ; Figure 5G), protein intake percentage ( $p = 0.658$ ,  $\eta^2 = 0.005$ ; Figure 5H), daily fat intake ( $p = 0.096$ ,  $\eta^2 = 0.026$ ; Figure 5I), fat intake normalized by body weight ( $p = 0.821$ ,  $\eta^2 = 0.002$ ; Figure 5J), and for fat intake ( $p = 0.252$ ,  $\eta^2 = 0.015$ ; Figure 5K).

The mean energy and macronutrients intake by sexes and by performance level can be found in supplementary Table S2 and Table S3 respectively.

Total compliance with current macronutrients recommendations was low for carbohydrates and high for fats and protein across the sample. Figure 6 represents the type of compliance level by sex and performance level.

Regarding compliance with the fat intake recommendations established by AESAN [42], overall adherence was moderate in the total sample. Specifically, 59.2% of participants met the recommendations, whereas 40.8% did not (6.5% consumed less fat than recommended and 34.2% exceeded the recommended intake). When compliance was compared by sex (Figure 6A), no significant differences were observed in adherence to fat intake recommendations ( $\chi^2 = 0.053$ ,  $p = 0.819$ , OR = 1.07, 95%CI: 0.594-1.93). Similarly, no significant differences were found in compliance across the different performance levels (Figure 6E;  $\chi^2 = 1.79$ ,  $p = 0.409$ ).

Overall compliance with carbohydrate intake recommendations from the ACSM/AND/DC guidelines [1] was very low, with only 9.8% of participants meeting the recommended intake and 90.2% consuming below the recommendations. When stratified by sex, a higher proportion of male athletes met the carbohydrate intake recommendations compared to females; however, this difference was not

statistically significant ( $\chi^2 = 2.57$ ,  $p = 0.109$ ; OR = 2.36, 95%CI = 0.81-6.92; Figure 6B). Regarding performance level, no significant differences were observed in compliance across the three levels ( $\chi^2 = 1.07$ ,  $p = 0.585$ ; Figure 6E).

Regarding protein intake compliance according to ACSM/AND/DC recommendations [1], 48.9% of participants met the recommended intake, while 51.1% did not (8.7% failed to reach the minimum recommended intake and 42.4% exceeded the protein recommendations). No significant differences were observed between sexes (Figure 6C;  $\chi^2 = 2.12$ ,  $p = 0.146$ , OR = 0.649, 95%CI = 0.362-1.16). Likewise, no significant differences were found across the different performance levels (Figure 6F;  $\chi^2 = 1.07$ ,  $p = 0.585$ ).

### 3.3.3. Micronutrient intake and compliance analysis

In terms of mineral intake, the mean intake was for calcium 1014.6 (520.0) mg/day, for iron 17.1 (6.7) mg/day, magnesium 386.0 (170.9) mg/day, and for zinc 11.7 (4.9) mg/day. For vitamins, the mean intake was for vitamin D 3.3 (1.1-8.8) mg/day, vitamin E 7.8 (5.6-11.8) mg/day, vitamin C 103.0 (47.0-174.2) mg/day, vitamin B1 1.6 (1.2-2.05) mg/day, vitamin B2 1.9 (0.8) mg/day, vitamin B3 38.3 (26.2-51.8) mg/day, vitamin B6 2.8 (1.2) mg/day, 312.7 (224.7-414.5)  $\mu$ g/day, and for vitamin B12 5.8 (3.7-9.2)  $\mu$ g/day. The mean intake by sexes and by performance level can be found in supplementary Table S4 and Table S5 respectively.

When comparing micronutrients intake between sexes (Table S4), significant differences were observed only for iron ( $p = 0.016$ ,  $d = 0.197$ ), magnesium ( $p < 0.001$ ,  $d = 0.501$ ), zinc ( $p = 0.001$ ,  $d = 0.490$ ), vitamin B1 ( $p = 0.002$ ,  $d = 0.404$ ), and vitamin B6 ( $p = 0.006$ ,  $d = 0.414$ ). In contrast, when intake was analysed across different performance levels (Table S5), significant differences were found only for iron ( $p = 0.047$ ,  $\eta^2 = 0.033$ ), vitamin E ( $p = 0.004$ ,  $\eta^2 = 0.058$ ), and vitamin B9 ( $p = 0.022$ ,  $\eta^2 = 0.041$ ).

The micronutrients with the lowest non-compliance rates were vitamin B3 (8.7 %), vitamin B6 (10.3 %), vitamin B12 (10.3 %), vitamin B1 (20.1 %), vitamin B2 (21.7 %) and iron (29.3 %). The micronutrients with a medium percentage of non-compliance rate are magnesium with (37.5 %), zinc (39.1 %) and, vitamin C (41.9 %) and, the micronutrients with the highest non-compliance rate are vitamin B9 (56.0 %), calcium (60.9 %), vitamin E (73.4 %) and vitamin D (77.2 %). The detailed data of compliance rates of micronutrients, is presented in Supplementary Table S6 and S7.

Sex-based significant differences in micronutrients compliance were limited to iron, magnesium, and vitamin B1, were females tended to have significantly lower compliance rates than males for iron ( $\chi^2 = 9.23$ ,  $p = 0.002$ , OR = 0.368, 95%CI = 0.191, 0.708), magnesium ( $\chi^2 = 6.75$ ,  $p = 0.009$ , OR = 0.449, 95%CI = 0.245, 0.825), and vitamin B1 ( $\chi^2 = 5.09$ ,  $p = 0.024$ , OR = 0.432, 95%CI = 0.206, 0.906).

When compliance was analysed according to competitive level, significant differences were observed for iron, vitamin B9 and vitamin E. When analysed according to competitive level, significant differences were found for iron ( $\chi^2 = 8.57$ ,  $p = 0.014$ ), vitamin B9 ( $\chi^2 = 7.13$ ,  $p = 0.028$ ) and vitamin E ( $\chi^2 = 6.94$ ,  $p =$

0.031). Iron compliance was highest among international athletes (100%), compared with national (69%) and regional competitors (65%). A progressive decrease in vitamin B9 compliance was observed from international (61%) to national (49%) and regional athletes (32%). For vitamin E, regional athletes showed the lowest compliance (15%), whereas international and national athletes presented similar adherence (33%).

### **3.4. Relationships between nutrition knowledge and dietary intakes**

Significant positive associations were observed between coaches' nutritional knowledge and athletes' dietary intake. Coaches' knowledge score was positively correlated with athletes' daily energy intake ( $r = 0.168$ ,  $p = 0.022$ , 95 % CI 0.024, 0.306) and daily carbohydrate intake ( $r = 0.199$ ,  $p = 0.007$ , 95 % CI 0.056, 0.334). When dietary intake was normalized by bodyweight, coaches' nutritional knowledge showed a positive association with carbohydrates intake ( $r = 0.248$ ,  $p < 0.001$ , 95 % CI 0.107, 0.379) and protein intake ( $r = 0.195$ ,  $p = 0.008$ , 95 % CI 0.052, 0.330).

Athletes' nutritional knowledge was not significantly associated with dietary intake variables or energy availability. However, a significant inverse association was found between coaches' and athletes' nutritional knowledge scores ( $r = -0.237$ ,  $p = 0.001$ , 95 % CI -0.359, -0.096).

All other non-significant associations are presented in Supplementary Table S8 and Table S9.

## **4. Discussion**

The present study provides a comprehensive evaluation of nutrition knowledge, dietary intake, and energy availability in athletes, while uniquely incorporating the influence of coaches' nutrition knowledge on athletes' dietary behaviours. The main findings indicate that, despite a moderate overall level of nutrition knowledge, athletes exhibited a low adherence to current macronutrient recommendations particularly for carbohydrates, and an alarmingly high prevalence of low energy availability. Importantly, athletes' nutrition knowledge was not associated with dietary intake or energy availability, whereas coaches' nutrition knowledge showed consistent positive associations with athletes' energy and macronutrient intake. Together, these findings highlight a critical disconnect between knowledge and practice in athletes and underscore the central role of coaches as key mediators of nutritional behaviours.

Athletes' nutrition knowledge should be considered a key determinant when interpreting dietary practices, as an adequate understanding of nutrition is essential for optimizing athletic performance. Conversely, insufficient nutrition knowledge may compromise dietary quality, nutrition status, and ultimately athletic performance [52]. Overall nutrition knowledge among athletes in the present study was classified as moderate, which is consistent with findings reported in reviews [9, 19, 22, 52–54] showing generally poor to moderate nutrition knowledge across many athletes groups, with frequent gaps in nutrition timing, hydration, and sports-specific guidelines.

The findings of our study indicate that athletes tend to overestimate their nutrition knowledge. This observation is consistent with previous research demonstrating that athletes with lower scores on questionnaires tend to overestimate their knowledge [9, 55].

Across questionnaire sections, the lowest scores were consistently observed in nutrition periodization reinforcing previous reports that athletes often struggle to translate general nutrition concepts into context-specific strategies aligned with understanding of the requirements of energy, macronutrients and micronutrients, and how these are modified during the season [7] and are unable to accurately identify the role of some nutrients in energy production, as the vast majority believed that proteins are used for energy production or that vitamins and minerals directly provide energy. This misconception appears to be widespread among athletes [8, 10]

Coaches achieved higher nutrition knowledge scores than athletes, particularly in the micronutrient, hydration section, and in the overall questionnaire. These findings align with those of previous research on coaches' nutrition knowledge in athletics trainers at a Division I university [56], rugby coaches [57], and the technical staff team of Spanish sport-team athletes [9]. However, they are lower than those observed in Finnish endurance coaches [14].

One of the most novel and impactful findings of this study is the differential relationship between nutrition knowledge and dietary intake depending on whether the knowledge resides in athletes or coaches. Athletes' nutrition knowledge was not associated with dietary intake, macronutrient distribution, or energy availability. In contrast, coaches' nutrition knowledge showed significant positive associations with athletes' total energy intake, carbohydrate intake, and carbohydrate and protein intake normalised by body weight whereas it was negatively correlated with athletes' nutrition knowledge.

The relationship between coaches' and athletes' nutrition knowledge is a critical factor influencing athletes' dietary behaviours, health, and performance. Coaches are often a primary source of nutrition information for athletes [14, 26, 58, 59]. However, some research [9, 14, 57, 60] consistently shows that coaches generally possess higher nutrition knowledge than athletes, but both groups frequently fall short of adequate knowledge thresholds.

Coaches' self-efficacy in nutrition counselling also mediates the quality of dietary recommendations provided to athletes [58] as their nutrition knowledge is linked to healthier dietary practices and improved nutrition knowledge among athletes [14, 61]. However, many coaches provide dietary advice despite insufficient nutrition training and relying on non-expert sources for nutrition information [58].

The absence of a relationship between athletes' nutrition knowledge and energy availability aligns with previous systematic reviews [15, 16] indicated that there is a weak to moderate positive association between nutrition knowledge and energy intake. Other study [29] have demonstrated that nutrition knowledge is a main factor to explain the risk of LEA. It is noteworthy that the research conducted by Burger et al., [62] revealed an inverse correlation between female nutrition knowledge and risk to develop LEA.

Despite moderate nutrition knowledge, dietary intake patterns in the present study were largely inconsistent with current sports nutrition recommendations [1]. Despite carbohydrates being the most crucial macronutrient for optimal athletic performance [63], carbohydrate intake was markedly below recommended levels in over 90% of athletes, regardless of sex or competitive level, a finding that mirrors previous research reporting chronic underconsumption of carbohydrates in athletic populations [64, 65], regardless of whether they are elite [66], sub-elite [67], or non-elite athletes [68].

In contrast, protein and fat intakes were generally within or above recommended ranges, reflecting a dietary pattern increasingly observed in athletes and potentially influenced by popular nutrition trends that prioritise protein intake while undervaluing the role of carbohydrates in performance [69].

A critical examination of the data reveals a concerning prevalence of athletes in a LEA state, affecting most of athletes. The results of studies examining the prevalence of LEA vary considerably depending on the methods used to measure energy expenditure and the levels of performance considered [4]. However, the overall prevalence is estimated to range from 22.0 % to 58.0 % [70] and by gender, 23.0 % to 79.5 % in females and 15.0 % to 70.0 % in males [4]. Also, our result suggests that, as the competitive level increases, the prevalence of LEA trends to be high, especially in national and international athletes, probably caused by the fact that at a higher performance level, athletes often face energy restriction due to intense training regimens and/or sport-specific body composition pressures [28, 4], and the highly competitive environment in elite sports encourages risky behaviours such as restrictive diets or overtraining that increase the prevalence of LEA [71].

Insufficient energy and carbohydrate intake in athletes poses a significant risk to their health, particularly in relation to their endocrine system and performance. In terms of performance, LEA may mitochondrial and muscle protein synthesis, endurance and strength, also training response, coordination and concentration [35, 72]. There are several endocrine concerns about LEA and dietary interventions should focus on addressing these hormonal imbalances, while women are more susceptible to compromised bone health than males due to menstrual dysfunctions, males also exhibit imbalances, especially in the hypothalamic-pituitary-gonadal axis which may cause hypogonadism [73].

These findings indicate that multiple factors modulate energy intake, EA and the risk to develop LEA and RED-S. It is important to highlight that nutrition plays a critical role in athletic performance and overall health. This underscores the value of implementing nutrition education programs for athletes [74]. Nutrition education for athletes has the potential to enhance several areas, including body composition [75–77], food behaviour [76, 77], dietary intakes for carbohydrates, energy, and EA [75]. Nutrition education programs could facilitate recovery in athletes who are experiencing LEA and RED-S symptoms [78].

Notwithstanding the advantages of nutrition education programs for athletes, there is no established intervention. Consequently, these should be developed and implemented on a case-by-case basis, in accordance with the specific requirements of each team and individual athlete, by a registered dietitian with expertise in sports nutrition [77].

## 4.1. Strength and limitations

Key strengths of this study include the simultaneous assessment of athletes and their coaches, the inclusion of athletes across multiple competitive levels, and the comprehensive evaluation of nutrition knowledge, dietary intake, and energy availability using validated tools.

However, several limitations should be acknowledged. The cross-sectional design precludes causal inference, dietary intake was self-reported and therefore subject to reporting bias, and the relatively small number of coaches limits generalisability. Additionally, energy availability was estimated rather than directly measured [79], although the methodology used aligns with current best practice in field-based research. Another limitation is the variability in the questionnaires to evaluate nutrition knowledge due to the lack of a validated and comprehensive questionnaire. This makes it challenging to compare and draw inferences between studies [8, 80]. As is the case with nutrition knowledge, it is challenging to infer from some other studies, due to the variability in the methods employed to record dietary intake [81]. The most used are food frequency questionnaires, 3-day recall, and 24h-recall [64, 81]. However, these methods tend to underestimate food intake, as they rely on athletes' memory or athletes may omit certain information from their diets [64, 81]. A key limitation of bioimpedance for estimating FFM is that its predictive equations rely on assumptions regarding hydration status, body water distribution, and body geometry, which may not hold outside the populations in which they were originally developed.

## 5. Conclusions

In conclusion, while athletes and coaches demonstrate moderate nutrition knowledge, this study reveals a high prevalence of LEA (68.5%) and chronically inadequate carbohydrate intake among athletes. A key finding is the disconnect between athletes' knowledge and their dietary practices, contrasted by the significant positive influence of coaches' nutrition knowledge on athletes' energy and macronutrient intake. These results underscore that athletes' nutritional is not solely determined by their own knowledge but is heavily mediated by their technical staff. Therefore, it is essential to implement comprehensive nutrition education programmes, led by registered dietitians and targeting both athletes and coaches to optimize health, mitigate LEA risks, and support athletic performance.

## Abbreviations

AND: Academy of Nutrition and Dietetics

ACSM: American College of Sports Medicine

DC: Dietitians of Canada

EA: Energy Availability

EI: Energy Intake

EEE: Exercise Energy Expenditure

FFM: Fat Free-Mass

LEA: Low Energy Availability

REDs: Relative Energy Deficiency

AEASN: Spanish Agency for Food Safety and Nutrition

NUKYA: Knowledge Questionnaire for Young and Adult Athletes.

## Declarations

### **Ethical approval:**

The study protocol was approved by the University of Valencia Human Ethics Committee (UV-INV\_ETICA-3260474). All participants provided written informed consent prior to participation and conducted in accordance with the Declaration of Helsinki.

### **Conflicts of interest:**

The authors have no financial or proprietary interests in any material discussed in this article.

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## Author Contribution

Conceptualization: Xavier Puchalt-Urbano and Jesús Blesa; Methodology: Xavier Puchalt-Urbano and Jesús Blesa; Formal analysis and investigation: Xavier Puchalt-Urbano; Writing – original draft preparation: Xavier Puchalt-Urbano; Writing – review and editing: María J. Esteve, Raúl López-Grueso, and Jesús Blesa; Supervision: Jesús Blesa, and Raúl López-Grueso

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## Data Availability

In alignment with Research Data Policies promoting open science, the dataset from this study is accessible to interested researchers via the Figshare repository:

<https://doi.org/10.6084/m9.figshare.32957471>

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## Figures

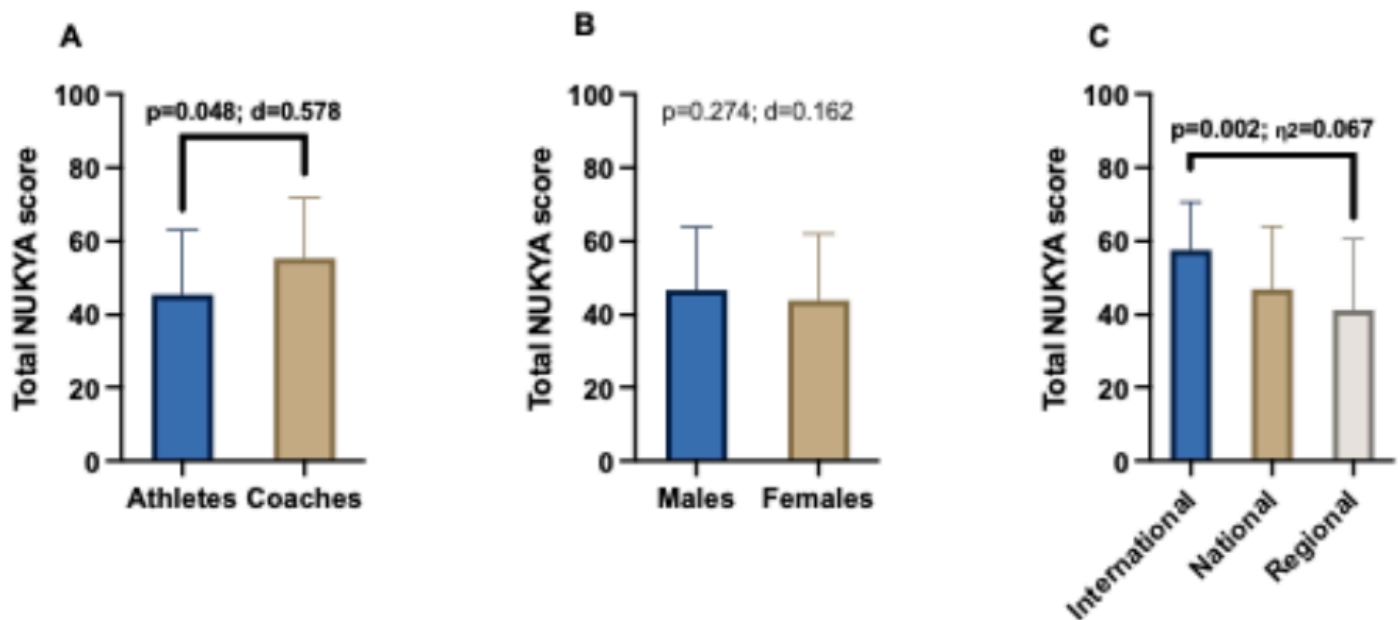


Figure 1

Comparison of total NUKYA scores between athletes and coaches (A), between males and females (B), and between performance level (C)

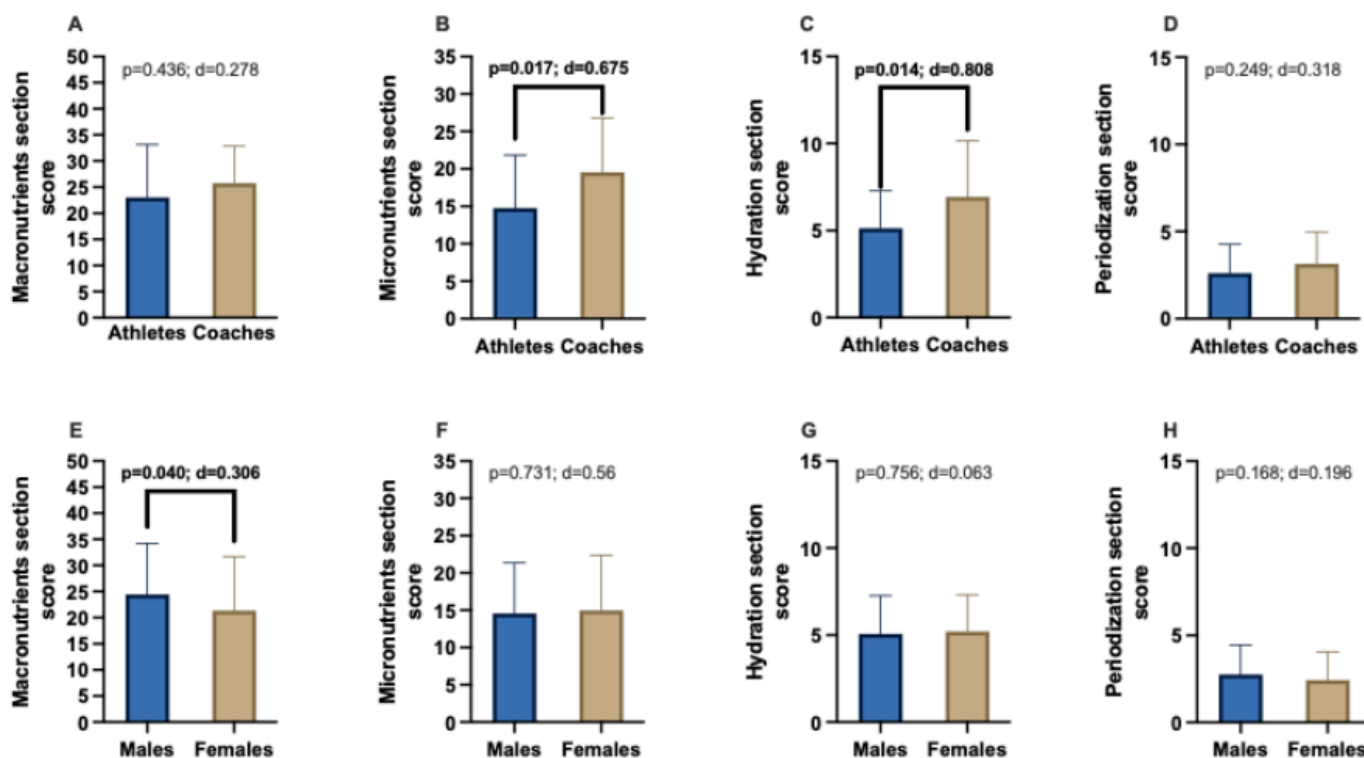


Figure 2

Differences in NUKYA section scores. Differences between athletes and coaches in macronutrients section (A), micronutrients section (B), hydration section (C), and periodization section (D); and differences between sex in macronutrients section (E), micronutrients section (F), hydration section (G), and periodization section (H). Bold P values and d indicate statistically significant results.

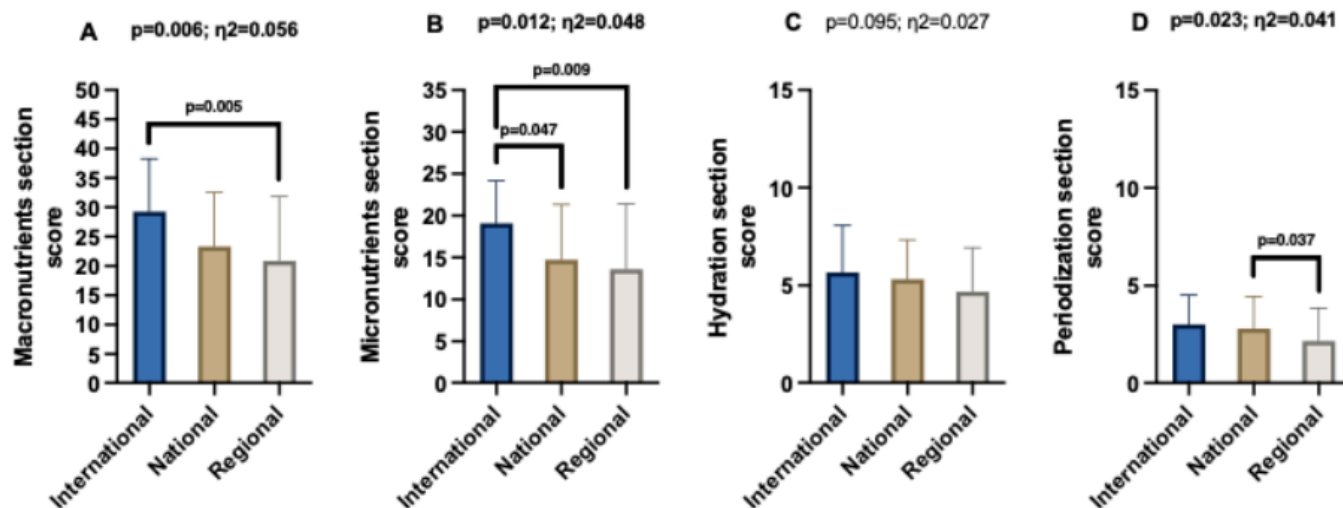


Figure 3

NUKYA section scores by performance level in macronutrients section (A), micronutrients section (B), hydration section (C), and periodization section (D). Bold P values and  $\eta^2$  indicate statistically significant results.

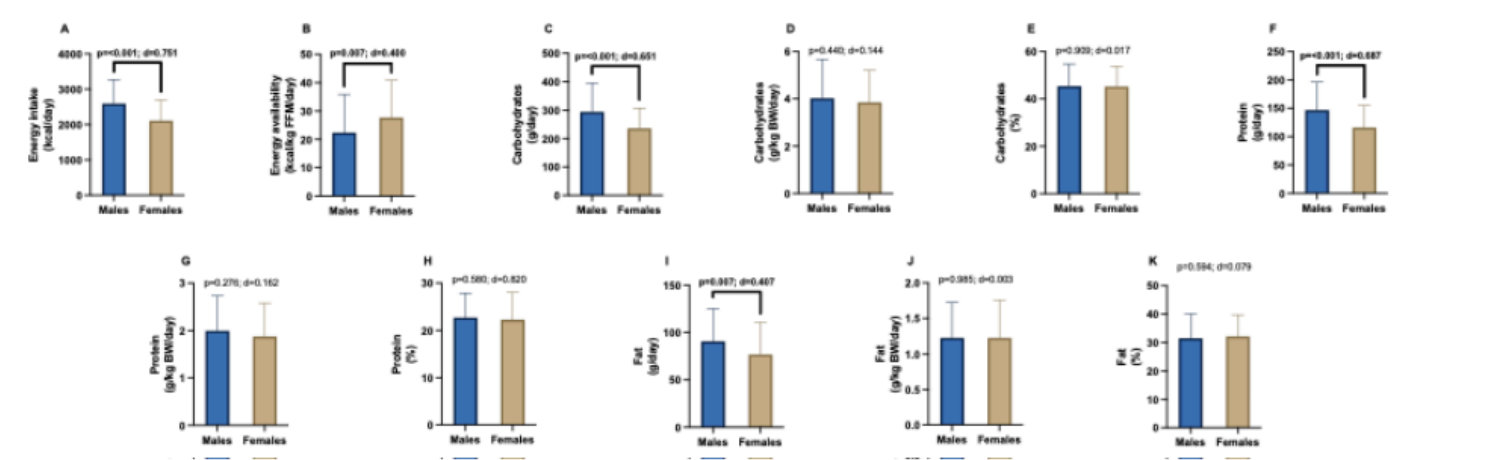


Figure 4

Differences in dietary intake between male and female athletes. Bold p values and d indicate statistically significant results.

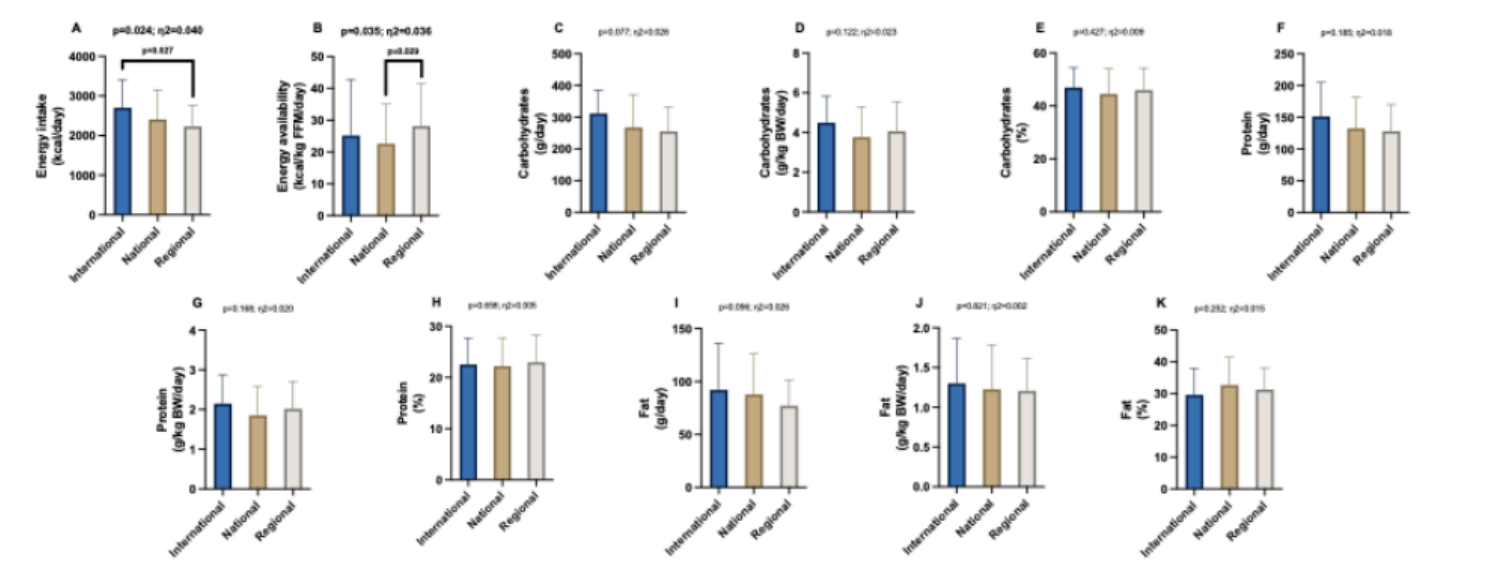


Figure 5

Differences in dietary intake between international, national and regional athletes. Bold p values and d indicate statistically significant results.

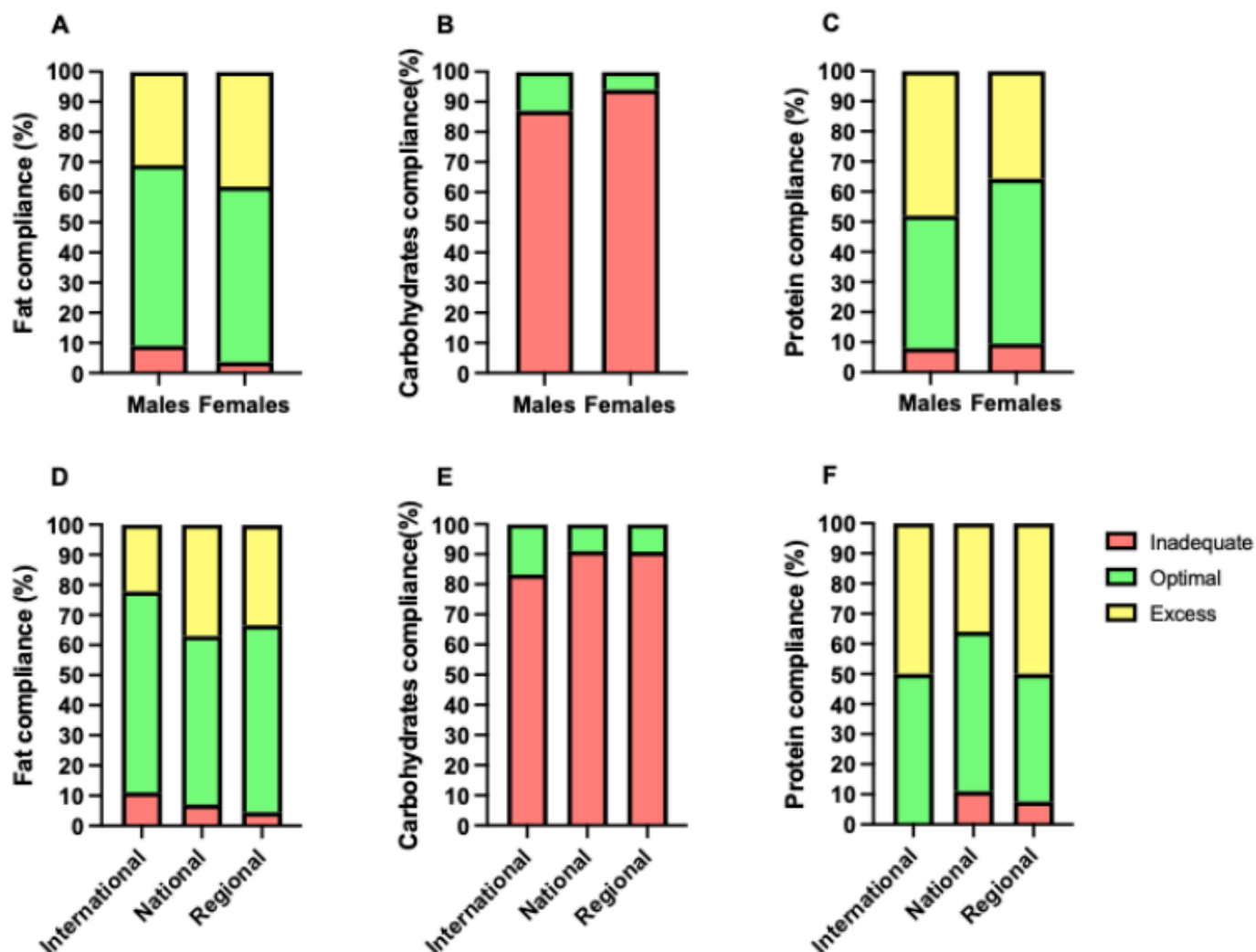


**Figure 6**

Compliance with fat, carbohydrate, and protein intake recommendations by sex (**A-C**) and by competitive level (**D-E**).

## Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [SupplementaryMaterial.docx](#)