




Article

# Association between Variation in Body Fat Mass Magnitude and Intake of Nutrients, including Carbohydrates, Fat, and B Vitamins, in a Cohort of Highly Trained Female Athletes

Marius Baranauskas <sup>1,\*</sup> , Ingrida Kupčiūnaitė <sup>1</sup>, Jurgita Lieponienė <sup>1</sup>  and Rimantas Stukas <sup>2</sup> 

<sup>1</sup> Faculty of Biomedical Sciences, State Higher Education Institution Panevėžys College, 35200 Panevėžys, Lithuania; ingrida.kupcunaite@panko.lt (I.K.); jurgita.lieponiene@panko.lt (J.L.)

<sup>2</sup> Department of Public Health, Institute of Health Sciences, Faculty of Medicine, Vilnius University, 01513 Vilnius, Lithuania; rimantas.stukas@mf.vu.lt

\* Correspondence: baranauskas.marius@panko.lt

**Abstract:** The most common sports nutrition strategies were constructed not only for maximizing musculoskeletal adaptations to exercise, but also to minimize health risks in athletes. Given the lack of research highlighting the potential effects of the intake of carbohydrates, fats, and B vitamins on body fat percentage in a population of female athletes, this study aimed to elucidate whether the intake of macronutrients and B vitamins could be associated with the variation in body fat percentage in a cohort of professional female athletes. This cross-sectional study was weighted to represent Lithuanian elite female athletes ( $n = 89$ ). The dietary assessment of the female athletes was carried out using a 3-day dietary recall method. Their body composition was assessed using the bioelectrical impedance analysis method. For females, the reported average intakes of energy, carbohydrates, protein, and fat were 2475 kcal/day, 5.1 g/kg/day, 1.5 g/kg/day, and 36.7%, respectively. Excess B vitamin intake was revealed, ranging within plus 1–2 standard deviations (SDs) around the mean requirements. As a consequence, excessive body fat percentage was potentially factored as a negative outcome in maintaining optimal body composition in female athletes. Multivariate logistic regression analysis of a sample of female athletes revealed that, despite a slightly positive energy balance ( $\Delta 95$  kcal/day), the carbohydrate-deficient diet (adjusted odds ratio (aOR) 0.3, 95% confidence interval (CI) 0.1; 0.7), along with higher intakes of vitamin B<sub>1</sub> (aOR 2.9, 95% CI 2.6; 7.8), vitamin B<sub>2</sub> (aOR 6.7, 95% CI 1.1; 8.3), and vitamin B<sub>3</sub> (aOR 1.8, 95% CI 1.4; 7.8) from food, was associated with a lower percentage of body fat. Therefore, more attention should be given to the intake of B vitamins in professional athletes with a range of body fat mass percentages for the purpose of achieving long-term goals of maintaining body composition and fitness.

**Keywords:** body fat mass; B vitamins; carbohydrates; fat; female athletes; food composition; nutrition



**Citation:** Baranauskas, M.; Kupčiūnaitė, I.; Lieponienė, J.; Stukas, R. Association between Variation in Body Fat Mass Magnitude and Intake of Nutrients, including Carbohydrates, Fat, and B Vitamins, in a Cohort of Highly Trained Female Athletes. *Foods* **2023**, *12*, 4152. <https://doi.org/10.3390/foods12224152>

Academic Editors: Joe Vinson, Ricardo Assunção and Mariana Santos

Received: 24 August 2023

Revised: 31 October 2023

Accepted: 14 November 2023

Published: 16 November 2023



**Copyright:** © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

## 1. Introduction

From the point of view of public health, people need to respond adequately to their nutritional needs in order to reduce the health-related risks of overweight and obesity [1]; thus, many nutritional recommendations have been proposed by healthcare professionals for the entire population at the global level [2,3]. Also, specific nutrition guidelines for the athletic population have been established due to a significant increase in physical loads and an increase in bodily energy demands [4]. The most common sports nutrition strategies were constructed not only for maximizing musculoskeletal adaptations to exercise, but also to minimize health risks in athletes [5].

In the present context, it should be noted that increased levels of physical activity have a meaningful impact on nutritional needs, particularly in terms of the intake of macronutrients and energy. Some sports make it difficult for athletes to consume the right quantity and type of food at the appropriate time. Thus, the nutrition goals for

athletes should rely on eating foods of adequate quality and quantity, with the intention of full replenishment of energy expenditure, to avoid sport-related malnutrition leading to exercise-induced fatigue [4]. Additionally, individual requirements for the intake of both macronutrients and micronutrients could vary depending on numerous factors, including not only the type of sport or age, but also possible sex disparities associated with the health status, physiology, and body composition of athletes [6–11]. More specifically, female athletes have a higher risk of low energy availability [9] and the athletic triad [8,9], and differ from male athletes in terms of their metabolic profiles [11], hormonal specificity (i.e., higher estrogen) [8,12], and body composition characteristics [13–15]. Female athletes are prone to greater body fat contents compared to male athletes [13–15].

Taking into consideration the fact that body composition, as a significant vector, can impact health status [16–19] and the efficiency of sports performance [20,21], a more supportive body composition profile (e.g., relatively lower fat percentage) could be beneficial for female athletes, especially for those playing weight-sensitive sports [13,22].

Nutritional strategies related to diets that are lower in calories and/or carbohydrates for optimizing the muscle-to-fat ratio are usually used in sports routines [23–35]. Some studies highlighting the effects of low-carbohydrate–high-fat diets on body composition have proposed that even with a large weight reduction, lean body mass is maintained and body fat mass is significantly reduced [36,37]. However, Valsdottir et al. reported controversial results indicating that the low-carbohydrate–high-fat diet had no superior effect on female body composition compared to a normal diet, with or without exercise [38]. Additionally, regardless of the impacts of macronutrients such as carbohydrates and fat on body fat mass levels, little is known about the relationship between specific B vitamins and body composition extremes in athletes. Vitamin B's key role in energy and lipid metabolism, triggering inflammatory responses and oxidative stress, and developing a higher risk for obesity, has been documented by scientific research [39–43]. However, while some observational studies have found a relationship between B vitamins—namely, B<sub>1</sub>, B<sub>2</sub>, B<sub>6</sub>, B<sub>9</sub>, and B<sub>12</sub>—and obesity [44–46], other studies showed no connection between B vitamins and body fat levels in non-athletic populations [47].

Given the inconsistency of the reported results in the entire population and the lack of research highlighting the potential effects of the consumption of carbohydrates, fat, and B vitamins on the body fat percentage in a population of female athletes, our study focused on exploring these associations and providing new evidence-based scientific results.

The aim of this study was to elucidate whether macronutrients and B vitamin intake could be associated with variations in body fat percentage in a cohort of professional female athletes.

The main objectives of this research were as follows:

- (1) To assess body composition in a sample of elite female athletes.
- (2) To evaluate the overall nutritional status of professional female athletes.
- (3) To investigate a possible relationship between nutritional intake and the magnitude of body fat mass in high-performance female athletes.

Thus, this study examined the following research questions (RQs) (Nomenclature table):

**RQ1.** *Do low-carbohydrate, high-fat diets relate to a lower body fat percentage?*

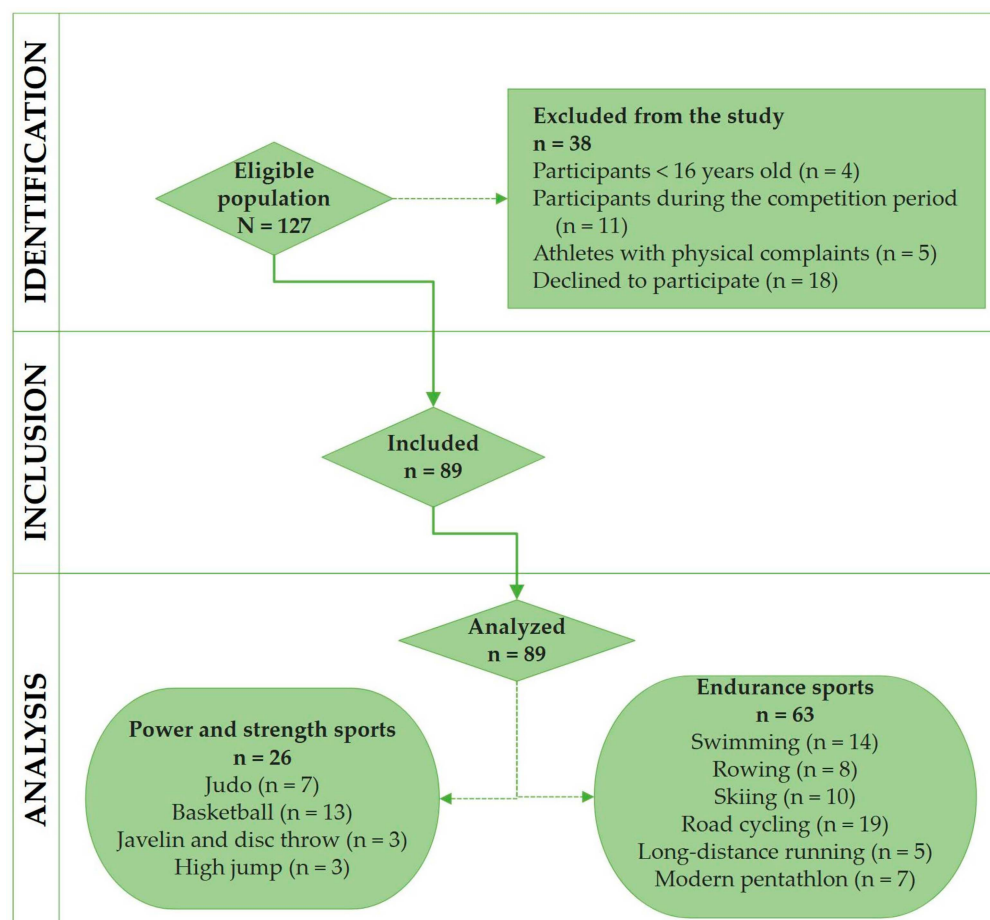
**RQ2.** *Are vitamin B (B<sub>1</sub>, B<sub>2</sub>, B<sub>3</sub>, B<sub>6</sub>, B<sub>9</sub>, and B<sub>12</sub>) intakes above the recommended dietary allowances (RDAs) associated with lower body fat in highly trained female athletes?*

## 2. Materials and Methods

### 2.1. Study Participants

A total of 127 female athletes of an eligible population were selected from a target population comprising 361 Lithuanian elite athletes. The representative sample size of 96 cases, by considering a 95% two-sided confidence interval (CI), was calculated [48]. The

probability sampling method was applied for the selection of the sample from the athletic population. Figure 1 provides more accurate information on the study enrollment process.



**Figure 1.** Study flowchart with exclusion criteria.

The participant inclusion criteria were as follows: (a) female athletes; (b) athletes who competed on a regular and organized basis; (c) participants of national and international competitions (candidates for the Olympics); (d) participants in the preparation phase; (e) participants who regularly followed a 6-day workout schedule plan for a week (training > 12 h a week); (f) participants who trained under four-year preparation programs derived from The National Olympic Committee; (g) participants taking no medications. The exclusion criteria were set as follows: (a) participants < 16 years old (junior athletes); (b) participants in the competition period; (c) athletes with physical complaints; (d) females without menstrual periods; (e) athletes who declined to participate in the study.

## 2.2. Body Composition Assessment

The measurements of height (m) and the core components of body composition were performed following a 4 h fasting window with no participation in moderate-intensity physical activities and with no alcohol and/or caffeine intake within 24 h [49]. All of the assessments were carried out by the same sports nutritionist at the Lithuanian Sports Medicine Center. Body composition was analyzed using the bioelectrical impedance approach referring to the third level of validity [50,51]. The multi-frequency bioelectrical impedance analysis method with frequencies ranging from 1 kHz to 1000 kHz was applied to predict both the intracellular and extracellular fluid values of the study participants. Thus, body mass (BM, kg, and %), body fat mass (BF, kg, and %), fat-free mass (FFM, kg, and %), and skeletal muscle mass (SMM, kg, and %) were estimated via an X-scan device (International Organization for Standardization adopted by the European Union (EN-ISO):

13488, Seoul, South Korea, <https://www.iso.org/home.html> (accessed on 15 November 2023)). The readings of the BIA device were generated from the specs of the impedance device, where, for commercial purposes, the equations were concealed from potential users.

The estimated percentages of both FFM (%) and SMM (%) were compared to the normative propositions set for females [52]. The FFM normative values for females range from 70% to 80%, while the SMM percentages vary between 64 and 80%. The BF percentages for female athletes fluctuate within ranges from <15% to 30–34%: ‘too low’ (<15%), ‘lean’ (15–19%), ‘optimal’ (20–24%), ‘acceptable’ (25–29%), and ‘excessive’ (30–34%). In addition, the muscle-to-fat ratio (MFR) of female athletes was evaluated by dividing SSM (kg) by BF (kg). The female athletes’ MFRs were graded based on ranges that specified an ‘insufficient’ MFR (<1.89), a ‘too small’ MFR (from 1.9 to 2.89), a ‘moderate’ MFR (from 3 to 3.99), an ‘extensive’ MFR (from 4 to 5), and a ‘maximum’ MFR (>5) [52].

### 2.3. Dietary Intake Assessment

A dietary assessment of female athletes was conducted using a standardized 3-day dietary recall method [53–56]. Detailed information regarding the total food amounts and beverages consumed by female athletes was obtained through structured interviews conducted by the sports dietician from the Lithuanian Sports Medicine Center. Participants were asked to provide details about the amounts of food they consumed and consider the size of portions by using plates, bowls, slices, tablespoons, cups, teaspoons, and grams in accordance with the Atlas of Food [57]. Female athletes were encouraged to provide recipes for the meal dishes they had consumed. Finally, energy and dietary macro- and micronutrient intakes were evaluated via the Nutrition Baseline Software (NutriSurvey, SEAMEO-TROPMED RCCN-University of Indonesia, <http://www.nutrisurvey.de/> (accessed on 5 April 2018)) [58]. The standard food database of NutriSurvey was manually complemented with the nutrition values of food items retrieved from the Lithuanian chemical composition tables [59].

The estimated energy requirement (EER) was calculated, aiming to identify the energy needs of female athletes [60]. Therefore, the Harris–Benedict equation [61] was applied to predict the resting metabolic rate (RMR). Furthermore, the training energy expenditure (TEE) was calculated in line with the guidance of the American Dietetic Association [4] and the Compendium of Physical Activities [62] developed to standardize the assignment of metabolic equivalent (MET) intensities in physical activity.

Nutritional adequacy was rated by comparing nutrient intakes to reference values (dietary reference intakes (DRIs)) established for planning and assessing diets for healthy athletes [63–65]. More specifically, for female athletes, the recommended dietary allowances (RDAs) for carbohydrate, protein, and fat intakes corresponded to 7–10 g/kg/day, 1.4–2.0 g/kg/day and 25–35%, respectively [63,64]. Given that an increased intake of micronutrients has little or no ergogenic effect on the athletic population, the consumption of vitamins and minerals should meet the RDAs documented for a target country. Consequently, an average daily B vitamin (B<sub>1</sub>, B<sub>2</sub>, B<sub>3</sub>, B<sub>6</sub>, B<sub>9</sub>, B<sub>12</sub>) intake among female athletes should be sufficient to meet only the RDAs [65]. On the condition that the RDAs were set at the estimated average requirements (EARs) plus twice the standard deviations (SDs) ( $RDA = EAR + 2 SD$ ) [66], both deficiencies and excesses in the dietary intake of nutrients in the sample of female athletes were identified in the cases where the mean dietary macro- and micronutrient intakes (after comparing them to the RDAs) fluctuated above minus or plus 2 SDs around mean requirements, respectively.

### 2.4. Statistical Analysis

The body composition outcomes, namely, BM, BF, FFM, SMM, and MFR, along with the intakes of energy, macronutrients (carbohydrates, protein, and fat), and micronutrients (vitamins B: B<sub>1</sub>, B<sub>2</sub>, B<sub>3</sub>, B<sub>6</sub>, B<sub>9</sub>, and B<sub>12</sub>) were presented as the means  $\pm$  SDs. Welch’s *t*-test (for unequal variances) was applied to compare the mean intensities of the body composition outcomes between the female athletes, who were allocated to subgroups of

power and strength sports as well as endurance sports. Nutritional adequacy was tested by comparing nutrient intakes to the RDAs. A one-sample *t*-test was used to determine whether there was a significant difference between the means of the two groups (intakes of energy and essential nutrients vs. RDAs). Furthermore, Cohen's *D* (*d*) estimates as effect sizes were calculated to support the results obtained from the *t*-tests. The *d* values were interpreted as follows:  $0 \leq |d| < 0.2$  ('trivial effect'),  $0.2 \leq |d| < 0.5$  ('small effect'),  $0.5 \leq |d| < 0.8$  ('moderate effect'),  $0.8 \leq |d|$  ('large effect'),  $1 \leq |d| < 2$  (the difference between the two means was larger than 1 SD),  $2 \leq |d|$  (the difference between the two means was larger than 2 SDs) [67].

Two multiple linear regression models, A and B, were obtained to assess the relationship between MFR as a dependent variable and independent variables such as BF (in kg) and SMM (in kg) in the cohorts of female athletes competing in power and strength sports or endurance sports.

Finally, a multivariate logistic regression model was constructed to calculate the adjusted odds ratios (aORs) and 95% confidence intervals (CIs) and to reveal whether an association exists between the intakes of essential nutrients and body fat mass as a dependent variable in female athletes. The dependent variable, namely, BF (in kg and %), of female athletes ( $23\% \geq |BF| > 23\%$ ) was converted to the dichotomous form (0—BF was below the median; 1—BF was equal to or larger than the median (reference category)). The units of the measurement of independent variables, namely, the intakes of energy (kcal/day), macronutrients (g/kg/day, %/day), and vitamin B (mg/day, mcg/day), were recorded to the dichotomous form, depending on the cut-off values that were calculated using the medians. The logistic regression model was adjusted to the sports branches of the study participants. The goodness-of-fit of the logistic regression model was evaluated using the Nagelkerke  $R^2$  ( $R^2_N$ ) statistic. All the analyses were performed via Statistical Package for the Social Sciences (IBM SPSS Statistics) version 25 (Armonk, NY, USA), and a two-sided *p*-value  $< 0.05$  was considered statistically significant. Statistical visualization was performed using Microsoft Visio Professional 2021 (Microsoft Corporation, Redmond, WA, USA).

### 3. Results

#### 3.1. Sample Characteristics

This cross-sectional study pooled 89 professional female athletes aged 18 to 31 ( $20.9 \pm 2.8$  years) who were engaged in endurance sports ( $n = 63$ ) as well as in power and strength sports ( $n = 26$ ), including swimming, rowing, skiing, road cycling, long-distance running, modern pentathlon, judo, basketball, javelin and disc throw, and high jump. All the female athletes were recruited only during the preparatory phase. The sports exercises were performed  $5.9 \pm 0.7$  days per week, while the mean duration of workout sessions was  $172.1 \pm 55.2$  min a day.

As shown in Table 1, BM amounted to  $62.0 \pm 10.5$  kg for female athletes. The means  $\pm$  SDs of FFM, SSM, BF, and MFR for the female athletes were  $76.9 \pm 4.2\%$ ,  $43.8 \pm 5.5\%$ ,  $23.0 \pm 4.2\%$ , and  $3.2 \pm 0.8$ , respectively.

The results of the *t*-test disclosed significant differences ( $p < 0.05$ ) associated with higher levels (in %) of BM, FFM, SMM, and BF in the subgroup of females from power and strength sports compared to those engaged in endurance sports.

The MFR ( $2.9 \pm 0.8$ ) of females from strength and power sports was significantly lower than the MFR ( $3.4 \pm 0.8$ ) of females from endurance sports, as was predicted by higher BF levels only classified as 'acceptable' (25–29%) for optimal athletic performance ( $p < 0.05$ ).

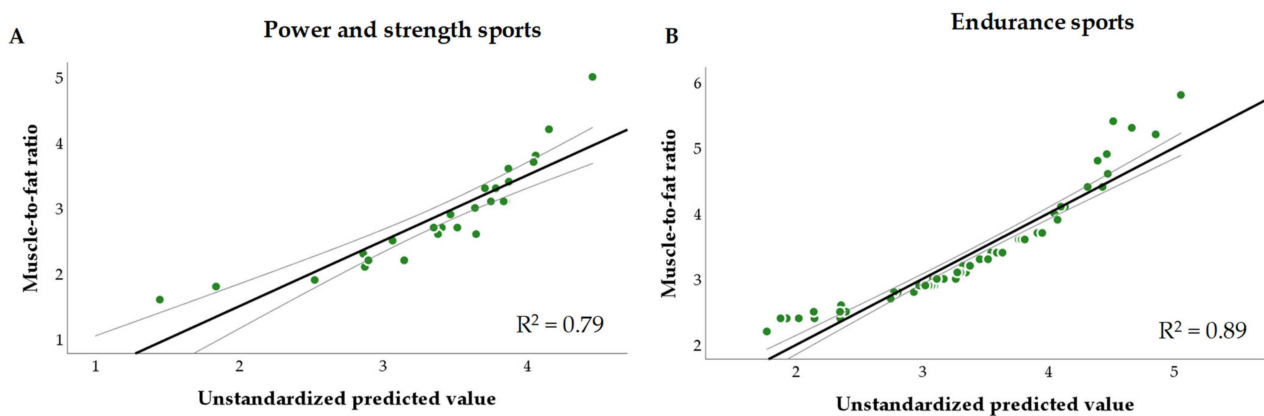
A more detailed data analysis revealed the relationship between MFR and body composition components such as SMM (in kg) and BF (in kg). Figure 2 shows the two multiple linear regression models, namely, A and B, included in the analysis.



**Table 1.** Body composition of female athletes according to sport branches.

| Height and Body Components | Power and Strength Sports (n = 26) | Endurance Sports (n = 63) |
|----------------------------|------------------------------------|---------------------------|
| H, m                       | 1.7 ± 0.1                          | 1.7 ± 0.2                 |
| BM, kg                     | 67.4 ± 14.3 *                      | 59.7 ± 7.5                |
| FFM, kg                    | 50.1 ± 7.9 *                       | 46.3 ± 4.7                |
| FFM%                       | 75.2 ± 4.9 *                       | 77.6 ± 3.7                |
| SMM, kg                    | 46.2 ± 7.2 *                       | 42.8 ± 4.3                |
| SMM, %                     | 69.4 ± 4.8 *                       | 72.1 ± 3.6                |
| BF, kg                     | 17.6 ± 7.1 **                      | 13.4 ± 3.5                |
| BF, %                      | 24.9 ± 4.8 *                       | 22.1 ± 3.6                |
| MFR                        | 2.9 ± 0.8                          | 3.4 ± 0.8 *               |

Data are presented as means ± SDs; SD—standard deviation; BM—body mass; FFM—fat-free mass; SMM—skeletal muscle mass; FM—fat-free mass; BMI—body mass index; MFR—muscle-to-fat ratio; H—height; \*— $p$ -value < 0.05; \*\*— $p$ -value < 0.01.



**Figure 2.** The association between MFR and body composition components, namely, SMM (in kg) and BF (in kg). (A) Multiple linear regression model A:  $F(2.23) = 42.4$ ,  $p < 0.0001$ ,  $R^2 = 0.79$ . (B) Multiple linear regression model B:  $F(2.62) = 232.3$ ,  $p < 0.0001$ ,  $R^2 = 0.89$ .

The linear regression analysis showed that female athletes participating in strength and power exercises had higher MFRs in an inverse association with excess adiposity ( $\beta -0.1$ , 95% CI:  $-0.15$ ;  $-0.07$ ). In the meantime, the female endurance athletes with higher MFRs depended on both lower fat mass ( $\beta -0.27$ , 95% CI:  $-0.3$ ;  $-0.2$ ) and higher skeletal muscle mass ( $\beta 0.08$ , 95% CI:  $0.06$ ;  $0.1$ ). Thus, in both cases, irrespective of the type of sports, an excessive body fat percentage was potentially factored as a negative outcome for maintaining the optimal body composition, and was considered a meaningful variable likely to influence physical fitness in female athletes. In addition, if the study subgroups by sports branches were heterogeneous according to the characteristics of body composition, the logistic regression model should be adjusted for sports branches, considered the main confounding variable during the forthcoming steps of the data analysis.

### 3.2. Energy, Macronutrient, and Micronutrient Intakes

Table 2 reveals the reported usual mean intakes of energy, carbohydrates, fats, proteins, and B vitamins in professional female athletes.

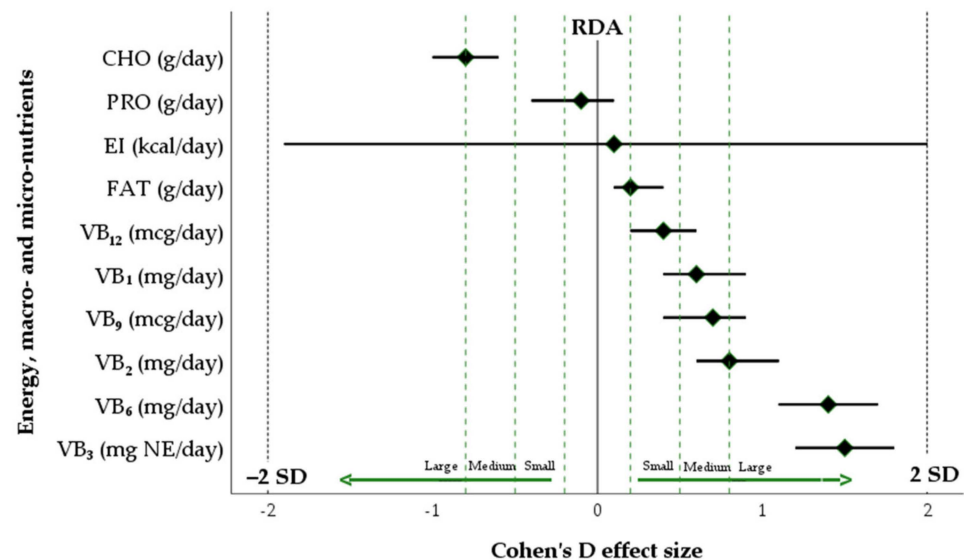
**Table 2.** Nutrient intakes in female athletes according to sport branches.

| Energy and Macro- and Micronutrients | Power and Strength Sports (n = 26) | Endurance Sports (n = 63) | RDAs           | $\Delta$ (95% CI) |
|--------------------------------------|------------------------------------|---------------------------|----------------|-------------------|
| EI, kcal/day                         | 2457 $\pm$ 628                     | 2480 $\pm$ 948            | 2501 $\pm$ 188 | 95 (−1607; 217)   |
| CHO, g/kg/day                        | 4.7 $\pm$ 1.7                      | 5.2 $\pm$ 2.6             | 7–10           | −1.9 (−2.4; −1.5) |
| PRO, g/kg/day                        | 1.4 $\pm$ 0.4                      | 1.5 $\pm$ 0.6             | 1.2–2.0        | −0.1 (−0.2; 0.0)  |
| FAT%                                 | 36.1 $\pm$ 7.4                     | 36.8 $\pm$ 7.8            | 25–35          | 1.6 (0.1; 3.2)    |
| VB <sub>1</sub> , mg/day             | 1.3 $\pm$ 0.5                      | 1.7 $\pm$ 0.9             | 1.1            | 0.5 (0.3; 0.6)    |
| VB <sub>2</sub> , mg/day             | 2.2 $\pm$ 0.9                      | 2.2 $\pm$ 1.2             | 1.3            | 0.9 (0.7; 1.2)    |
| VB <sub>3</sub> , mg NE/day          | 20 $\pm$ 4.6                       | 21.5 $\pm$ 9.6            | 8              | 13 (11.2; 14.8)   |
| VB <sub>6</sub> , mg/day             | 2.6 $\pm$ 0.5                      | 2.6 $\pm$ 1.1             | 1.3            | 1.3 (1.1; 1.5)    |
| VB <sub>9</sub> , mcg/day            | 219.7 $\pm$ 71.5                   | 215.1 $\pm$ 92.4          | 200            | 16.4 (−1.8; 34.6) |
| VB <sub>12</sub> , mcg/day           | 5.9 $\pm$ 3.3                      | 3.9 $\pm$ 2.3             | 3              | 1.5 (0.7; 2.3)    |

Data are presented as means  $\pm$  SDs; SD—standard deviation; EI—energy intake; CHO—carbohydrates; PRO—protein; FAT—fat; V—vitamin; NE—niacin equivalent; RDA—recommended dietary allowance; average daily level of intake sufficient to meet the nutrient requirements for nearly all (97–98%) healthy individuals;  $\Delta$ —the mean differences in dietary macro- and micronutrient intakes compared to the RDAs; 95% CI—95% confidence interval.

For females, the reported average intakes of energy, carbohydrates, protein, and fat were 2475  $\pm$  864 kcal/day, 5.1  $\pm$  2.4 g/kg/day, 1.5  $\pm$  0.5 g/kg/day, and 36.7  $\pm$  7.5%, respectively. Furthermore, the mean amounts of B vitamins consumed by female athletes were reported as follows: vitamin B<sub>1</sub> (1.6  $\pm$  0.8 mg/day), vitamin B<sub>2</sub> (2.2  $\pm$  1.1 mg/day), vitamin B<sub>3</sub> (21  $\pm$  8.5 mg NE/day), vitamin B<sub>6</sub> (2.6  $\pm$  0.9 mg/day), vitamin B<sub>9</sub> (216.4  $\pm$  86.4 mcg/day), vitamin B<sub>12</sub> (4.5  $\pm$  4.0 mcg/day).

As indicated in Figure 3, when comparing nutrient intakes to the RDAs, only a carbohydrate-deficient diet was identified in female athletes. Despite a slightly positive energy balance ( $\Delta$  95 kcal/day, 95% CI: −1607; 217), as compensation led by the insufficient intake of carbohydrates, a high-fat diet consisting of more than 36% of the total calories was consumed by the study participants.

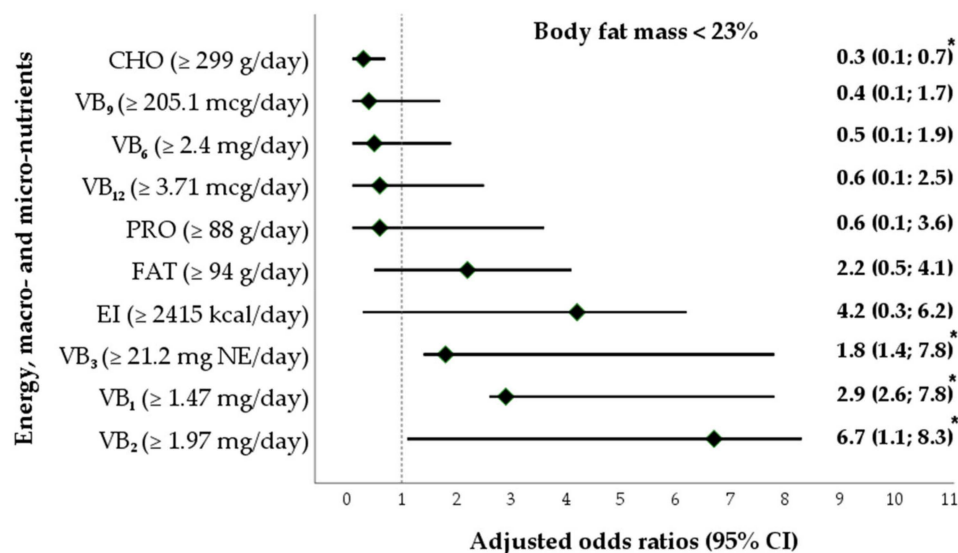


**Figure 3.** The measure of Cohen's D reporting the effect size of the mean differences in dietary macro- and micronutrient intakes after comparing them to the RDAs. CHO—carbohydrates; FAT—fat; EI—energy intake; V—vitamin; NE—niacin equivalent; RDA—recommended dietary allowance; SD—standard deviation.

### 3.3. Association between Nutrient Intakes and Body Fat Mass

As shown in Figure 4, the analysis included one multivariate logistic regression model. After adjustment for the sports disciplines, lower intakes of carbohydrates were associated

with lower odds of having a lower body fat percentage (aOR 0.3, 95% CI 0.1; 0.7). In addition, the assessment of the sample of female athletes showed that the aORs for the lower percentage of body fat were related to higher intakes of vitamin B<sub>1</sub> (aOR = 2.9, 95% CI 2.6; 7.8), vitamin B<sub>2</sub> (aOR 6.7, 95% CI 1.1; 8.3), and vitamin B<sub>3</sub> (aOR 1.8, 95% CI 1.4; 7.8).



**Figure 4.** The association between the intake of energy, macronutrients, and B vitamins (B<sub>1</sub>, B<sub>2</sub>, B<sub>3</sub>, B<sub>6</sub>, B<sub>9</sub>, B<sub>12</sub>) and body fat mass as dependent variables in female athletes (multivariate analyses). CHO—carbohydrates; FAT—fat; EI—energy intake; V—vitamin; NE—niacin equivalent; V—vitamin; aOR—adjusted odds ratio =  $e^{\beta}$ ; 95% CI—95% confidence interval; \*— $p$ -value < 0.05.

Figure 4 reflects that the adjusted odds ratios (aORs) and their 95% confidence intervals (CIs) (min; max) for the macro- and the specified micronutrient intake predicted lower body fat percentage. If aORs, including values of 95% CI, were higher than 1 or lower than 1, a positive or negative association between the variables was determined, respectively. If the aORs crossed the dotted line, there was no association between the variables under analysis. The magnitude of the aORs was not interpreted in an ascending or a descending manner.

The reference category was body fat mass  $\geq 23\%$ . The logistic regression model was adjusted for the sports branches of the female athletes. The measure of goodness of fit in the logistic regression analysis was  $R^2_N = 0.28$ ;  $p = 0.28$ .

#### 4. Discussion

While conducting this cross-sectional study, we examined the association between the variation in body fat mass magnitude and the intake of nutrients, including carbohydrates, fat, and B vitamins, in a cohort of highly trained female athletes from Lithuania.

Our findings showed that despite a slightly positive energy balance ( $\Delta$  95 kcal/day), carbohydrate-deficient diets along with higher intakes of vitamin B<sub>1</sub>, vitamin B<sub>2</sub>, and vitamin B<sub>3</sub> from food were associated with lower body fat percentage in female athletes. The results of similar studies carried out in other countries, such as Canada [23,24], Poland [25,26], Brazil [27], Portugal [28], Australia [29], Spain [30], the Netherlands [21], the United Kingdom [32], Mexico [33], the United States [34], and Indonesia [35], have shown that athletes regularly consumed high-fat foods (ranging from 27% to 37%), which easily contributed to the insufficient intake of carbohydrates (ranging from 2.4 g/kg to 6.6 g/kg). The results of our study were also consistent with those obtained by other researchers and revealed an inadequate intake of carbohydrates ( $\sim 5$  g/kg vs. 7–10 g/kg), notwithstanding the fact that Lithuanian elite female athletes were engaged in physical activities of 2–3 h training with moderate–high intensity.



It should also be highlighted that there is some scientific evidence referring to the potential benefits of low-carbohydrate diets in cases where liver and muscle glycogen stores in athletes have not been fully replenished as a result of exercise [68–70]. Therefore, such conditions may be potentially associated with long-term bodily adaptations to augment fatty acid oxidation rates via the promotion of mitochondrial biogenesis [71]. In our case, the participation of female athletes in physical activity accompanied by the training method ‘training low’ was spontaneous. It is worth mentioning that ‘training low’ as a training–nutrition strategy [72], designed to purposefully deplete muscle glycogen stores due to the reduced availability of exogenous carbohydrates along with a peptide hormone, namely, insulin, may contribute to the occurrence of alterations in lipid metabolism and trigger both lipolysis and the mobilization of fatty acids. Although the relationship between the usual isocaloric low-carbohydrate diets and lower body fat percentage was confirmed by our study, major concerns remain due to the inadequate intake of dietary carbohydrates around exercise, in line with the possibility of contributing to rapid fatigue in the central nervous system and a negative impact on the immune system [73] and aerobic fitness [74,75]. For these reasons, low-carbohydrate diets have still not been recommended for professional athletes.

Low-carbohydrate diets were associated with an increased fat intake according to our study sample. Although high-fat diets do not adversely affect traditional lipid parameters such as plasma triglycerides and low- and high-density lipoprotein cholesterol profiles in athlete populations [76], there is scientific evidence revealing a positive correlation between the fat intake and the increased levels of circulating homocysteine acting as a cardiometabolic risk factor [77,78]. Thus, our study speculates on a meaningful issue related to the nutritional goal to be assigned to the athletic population as a recommendation for a change from a high-fat isocaloric diet consisting of ~36% of total calories from fats to a high-carbohydrate diet. Furthermore, in line with this recommendation, it must be highlighted that following scientific research, the decrease in circulating homocysteine was also related to the increased consumption of B vitamins, such as B<sub>2</sub>, B<sub>6</sub>, B<sub>9</sub>, and B<sub>12</sub>, which were recognized as cofactors of enzymes engaged in homocysteine metabolism [79–82].

Finally, B vitamins play a significant part in biological processes [83] and energy metabolism [39,84]. If the consumed amount falls below the RDA for B vitamins (B<sub>1</sub>, B<sub>2</sub>, B<sub>6</sub>, and B<sub>9</sub>), the physical body may suffer from a micronutrient deficiency likely to lead to the disturbances in energy metabolism, and consequently, cause fat accumulation as well as potentially increased adipose tissue [44–46,85–87]. In our case, the levels of B vitamins consumed by female athletes did not differ from the RDAs; therefore, these findings were consistent with current studies reporting a good status for vitamins B<sub>6</sub>, B<sub>9</sub>, and B<sub>12</sub> in highly active females [88,89]. Also, the multivariate logistic regression analysis disclosed an association between a higher intake of B vitamins, namely, B<sub>1</sub>, B<sub>2</sub>, and B<sub>3</sub>, and lower body fat among female athletes. The explanatory mechanisms between the development of body fat and higher intakes of vitamin B<sub>1</sub>, vitamin B<sub>2</sub>, and vitamin B<sub>3</sub> have not yet been clarified in the athletic population. The predictable and only possible pathways have been speculated to explore the relationship between vitamin B levels and the progress of body fat mass in the non-athletic population [39,84,90–92].

## 5. Strengths and Limitations

Our study has some strengths, as it prioritized the nutritional care of female athletes playing different sports. This study has, for the first time, contributed to the evidence of a relationship between variation in body fat mass magnitude and the intake of selected nutrients from food, specifically, carbohydrates and vitamins B<sub>1</sub>, B<sub>2</sub>, and B<sub>3</sub>. Consequently, athletes pursuing long-term body composition goals (in terms of the optimal muscle-to-fat ratio) can benefit from food sources of vitamin B<sub>1</sub> and carbohydrates, including green vegetables, whole-grain products, and rice bran rather than meat [93]. On the other hand, the intake of vitamins B<sub>2</sub> and B<sub>3</sub> in conjunction with protein may be increased by eating a diet rich in foods such as milk, eggs, and lean meats [93].

This study has some limitations. First, it would be more accurate to detect vitamin B levels in blood serum or whole blood; therefore, further studies should lay emphasis on the association between plasma concentrations of B vitamins and the variation in body fat levels in the athletic population. Second, as genetics and sport selection are confounding variables when it comes to establishing what determines body fat, it is not possible to conclude that (a) a lower-carbohydrate diet will lead to lower body fat, and (b) higher intakes of vitamin B<sub>1</sub>, vitamin B<sub>2</sub>, and vitamin B<sub>3</sub> lead to increased body fat. On the condition that the study was cross-sectional in design and unfitted to figure out cause-and-effect, there remains a necessity for further randomized experimental studies to validate the effect of B vitamin intake on adipose tissue development and metabolism. Third, as our study represented only elite athletes, the estimated representative sample size was relatively small. Finally, the main study participants were female athletes; therefore, sports professionals should be cautious when extrapolating the empirical data to male athletes or non-athletic populations.

Taking into account that current research on vitamin B and fat metabolism is restricted and incompatible, further studies are needed to confirm the relationship between the intake of different B vitamins and the adiposity levels in a wider athletic population. Additionally, this study supports further hypotheses in future research that rely on how the supplementation with B vitamins can possibly result in a reduction in body weight gain, thus promoting potential benefits to professional athletes following long-term goals for body composition and fitness [46,75].

## 6. Conclusions

As an important part of triggering the adaptations to endurance or power and strength training, elite female athletes did not maintain a diet high in carbohydrates. The Western-like low-carbohydrate (~5 g/kg/day) isocaloric diet, consisting of at least 36% of total calories from fats, was consumed by the sample of female athletes.

Despite a slightly positive energy balance ( $\Delta$  95 kcal/day), the carbohydrate-deficient diet, along with higher intakes of vitamin B<sub>1</sub>, vitamin B<sub>2</sub>, and vitamin B<sub>3</sub> from food, was associated with a lower percentage of body fat in our cohort of female athletes. Therefore, when female athletes with a higher body fat percentage attempt to achieve optimal body composition by limiting carbohydrates, they should be cognizant of potentially shortening their intake of protein and specific B vitamins.

**Author Contributions:** Conceptualization, M.B., I.K. and R.S.; methodology, M.B. and I.K.; software, J.L. and M.B.; validation, M.B., I.K. and R.S.; formal analysis, R.S., M.B. and I.K.; investigation, M.B.; resources, M.B., I.K., J.L. and R.S.; data curation, M.B. and I.K.; writing—original draft preparation, M.B.; writing—review and editing, R.S., I.K. and M.B.; visualization, M.B. and J.L.; supervision, M.B. and I.K.; project administration, I.K., J.L. and R.S. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** This study was conducted in accordance with the Declaration of Helsinki, and approved by the Vilnius Regional Committee of Biomedical Research Ethics (protocol code 158200-17-898-419, of 11 April 2017).

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

**Data Availability Statement:** Data is contained within the article.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Nomenclature

Acronyms and terminology

| Term     | Definition                       |
|----------|----------------------------------|
| $\Delta$ | Delta                            |
| aOR      | Adjusted Odds Ratio              |
| BIA      | Bioelectrical Impedance Analysis |

|                             |  |
|-----------------------------|--|
| BM                          | Body Mass  |
| BF                          | Body Fat   |
| CHO                         | Carbohydrates  |
| CI                          | Confidence Interval  |
| D                           | Cohen's D Effect Size  |
| DRI                         | Dietary Reference Intake   |
| EAR                         | Estimated Average Requirement  |
| EER                         | Estimated Energy Requirement   |
| EI                          | Energy Intake  |
| EN-ISO                      | International Organization for Standardization adopted by the European Union |
| FAT                         | Fat  |
| H                           | Height   |
| FFM                         | Fat-Free Mass  |
| R <sup>2</sup> <sub>N</sub> | Nagelkerke R <sup>2</sup>  |
| RDA                         | Recommended Dietary Allowance  |
| RQ                          | Research Question  |
| kHz                         | Kilohertz  |
| MET                         | Metabolic Equivalent   |
| MFR                         | Muscle-to-Fat Ratio  |
| NE                          | Niacin Equivalent  |
| <i>p</i>                    | <i>p</i> -value  |
| PRO                         | Protein  |
| RMR                         | Resting Metabolic Rate   |
| SD                          | Standard Deviation   |
| SMM                         | Skeletal Muscle Mass   |
| SPSS                        | Statistical Package for the Social Sciences                                  |
| TEE                         | Training Energy Expenditure  |
| USA                         | The United States of America   |
| V                           | Vitamin  |
| vs.                         | Versus   |

## References

1. World Health Organization. Obesity and Overweight. Available online: <https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight> (accessed on 3 August 2023).
2. Singer, P.; Blaser, A.R.; Berger, M.M.; Calder, P.C.; Casaer, M.; Hiesmayr, M.; Mayer, K.; Montejo, J.C.; Pichard, C.; Preiser, J.-C.; et al. ESPEN guideline on clinical nutrition in the intensive care unit. *Clin. Nutr.* **2019**, *38*, 48–79. [\[CrossRef\]](#)
3. Hassapidou, M.; Vlassopoulos, A.; Kalliostra, M.; Govers, E.; Mulrooney, H.; Ells, L.; Salas, X.R.; Muscogiuri, G.; Darleska, T.H.; Busetto, L.; et al. European Association for the study of obesity position statement on medical nutrition therapy for the management of overweight and obesity in adults developed in collaboration with the European federation of the associations of dietitians. *Obes. Facts* **2023**, *16*, 11–28. [\[CrossRef\]](#)
4. Thomas, D.T.; Erdman, K.A.; Burke, L.M. American College of Sports Medicine Joint Position Statement. Nutrition and athletic performance. *Med. Sci. Sports Exerc.* **2016**, *48*, 543–568. [\[PubMed\]](#)
5. International Olympic Committee. IOC consensus statement on sports nutrition 2010. *Int. J. Sport Nutr. Exerc. Metab.* **2010**, *29*, S3–S4.
6. De Souza, M.J.; Williams, N.I.; Nattiv, A.; Joy, E.; Misra, M.; Loucks, A.B.; Olmsted, M.P.; Barrack, M.; Mallinson, R.J.; Gibbs, J.C.; et al. Misunderstanding the female athlete triad: Refuting the IOC consensus statement on relative energy deficiency in sport (RED-S). *Br. J. Sports Med.* **2014**, *48*, 1461–1465. [\[CrossRef\]](#) [\[PubMed\]](#)
7. Holtzman, B.; Ackerman, K.E. Recommendations and nutritional considerations for female athletes: Health and performance. *Sports Med.* **2021**, *51*, 43–57. [\[CrossRef\]](#)
8. Nattiv, A.; Loucks, A.B.; Manore, M.M.; Sanborn, C.F.; Sundgot-Borgen, J.; Warren, M.P. American College of Sports Medicine position stand: The female athlete triad. *Med. Sci. Sports Exerc.* **2007**, *39*, 1867–1882.
9. Ackerman, K.E.; Holtzman, B.; Cooper, K.M.; Flynn, E.F.; Bruinvels, G.; Tenforde, A.S.; Popp, K.L.; Simpkin, A.J.; Parziale, A.L. Low energy availability surrogates correlate with health and performance consequences of relative energy deficiency in sport. *Br. J. Sports Med.* **2019**, *53*, 628–633. [\[CrossRef\]](#) [\[PubMed\]](#)
10. De Souza, M.J.; Nattiv, A.; Joy, E.; Misra, M.; Williams, N.I.; Mallinson, R.J.; Gibbs, J.C.; Marion Olmsted, M.; Goolsby, M.; Matheson, G. 2014 female athlete triad coalition consensus statement on treatment and return to play of the female athlete triad: 1st international conference held in San Francisco, California, May 2012 and 2nd international conference held in Indianapolis, Indiana, May 2013. *Br. J. Sports Med.* **2014**, *48*, 289.

11. Al-Khelaifi, F.; Diboun, I.; Donati, F.; Botrè, F.; Alsayrafi, M.; Georgakopoulos, C.; Suhre, K.; Yousri, N.A.; Elrayess, M.A. A pilot study comparing the metabolic profiles of elite-level athletes from different sporting disciplines. *Sports Med. Open* **2018**, *4*, 2. [[CrossRef](#)]
12. Karastergiou, K.; Smith, S.R.; Greenberg, A.S.; Fried, S.K. Sex differences in human adipose tissues—The biology of pear shape. *Biol. Sex. Differ.* **2012**, *3*, 13. [[CrossRef](#)]
13. Sansone, P.; Makivic, B.; Csapo, R.; Hume, P.; Martínez-Rodríguez, A.; Bauer, P. Body fat of basketball players: A systematic review and meta-analysis. *Sports Med. Open* **2022**, *8*, 26. [[CrossRef](#)] [[PubMed](#)]
14. Scanlan, A.T.; Dascombe, B.J.; Kidcaff, A.P.; Peucker, J.L.; Dalbo, V.J. Gender-specific activity demands experienced during semiprofessional basketball game play. *Int. J. Sports Physiol. Perform.* **2015**, *10*, 618–625. [[CrossRef](#)] [[PubMed](#)]
15. Ziv, G.; Lidor, R. Physical attributes, physiological characteristics, on-court performances and nutritional strategies of female and male basketball players. *Sports Med.* **2009**, *39*, 547–568. [[CrossRef](#)] [[PubMed](#)]
16. Ackland, T.R.; Lohman, T.G.; Sundgot-Borgen, J.; Maughan, R.J.; Meyer, N.L.; Stewart, A.D.; Müller, W. Current status of body composition assessment in sport: Review and position statement on behalf of the ad hoc research working group on body composition health and performance, under the auspices of the IOC Medical Commission. *Sports Med.* **2012**, *42*, 227–249. [[CrossRef](#)] [[PubMed](#)]
17. Kershaw, E.E.; Flier, J.S. Adipose tissue as an endocrine organ. *J. Clin. Endocrinol. Metab.* **2004**, *89*, 2548–2556. [[CrossRef](#)]
18. Guh, D.P.; Zhang, W.; Bansback, N.; Amarsi, Z.; Birmingham, C.L.; Anis, A.H. The incidence of comorbidities related to obesity and overweight: A systematic review and meta-analysis. *BMC Public Health* **2009**, *9*, 88. [[CrossRef](#)]
19. Harvey, I.; Boudreau, A.; Stephens, J.M. Adipose tissue in health and disease. *Open Biol.* **2020**, *10*, 200291. [[CrossRef](#)]
20. Sundgot-Borgen, J.; Meyer, N.L.; Lohman, T.G.; Ackland, T.R.; Maughan, R.J.; Stewart, A.D.; Müller, W. How to minimize the health risks to athletes who compete in weight-sensitive sports review and position statement on behalf of the Ad Hoc Research Working Group on Body Composition, Health and Performance, under the auspices of the IOC Medical Commission. *Br. J. Sports Med.* **2013**, *47*, 1012–1022. [[CrossRef](#)]
21. Gabbett, T.J. Science of rugby league football: A review. *J. Sports Sci.* **2005**, *23*, 961–976. [[CrossRef](#)]
22. Martinsen, M.; Sundgot-Borgen, J. Higher prevalence of eating disorders among adolescent elite athletes than controls. *Med. Sci. Sports Exerc.* **2013**, *45*, 1188–1197. [[CrossRef](#)]
23. Masson, G.; Lamarche, B. Many non-elite multisport endurance athletes do not meet sports nutrition recommendations for carbohydrates. *Appl. Physiol. Nutr. Metab.* **2016**, *41*, 728–734. [[CrossRef](#)]
24. Bell, M.; Ghatora, R.; Retsidou, M.I.; Chatzigianni, E.; Klentrou, P. Energy expenditure, dietary energy intake, and nutritional supplements in adolescent volleyball athletes versus nonathletic controls. *Nutrients* **2023**, *15*, 1788. [[CrossRef](#)]
25. Pilis, K.; Stec, K.; Pilis, A.; Mroczek, A.; Michalski, C.; Pilis, W. Body composition and nutrition of female athletes. *Rocz. Panstw. Zakl. Hig.* **2019**, *70*, 243–251. [[CrossRef](#)]
26. Zapolska, J.; Witczak, K.; Manczuk, A.; Ostrowska, L. Assessment of nutrition, supplementation and body composition parameters on the example of professional volleyball players. *Rocz. Panstw. Zakl. Hig.* **2014**, *65*, 235–242.
27. Coutinho, L.A.; Porto, C.P.; Pierucci, A.P. Critical evaluation of food intake and energy balance in young modern pentathlon athletes: A cross-sectional study. *J. Int. Soc. Sports Nutr.* **2016**, *13*, 15. [[CrossRef](#)] [[PubMed](#)]
28. Nunes, C.L.; Matias, C.N.; Santos, D.A.; Morgado, J.P.; Monteiro, C.P.; Sousa, M.; Minderico, C.S.; Rocha, P.M.; St-Onge, M.-P.; Sardinha, L.B.; et al. Characterization and comparison of nutritional intake between preparatory and competitive phase of highly trained athletes. *Medicina* **2018**, *54*, 41. [[CrossRef](#)]
29. Jenner, S.L.; Trakman, G.; Coutts, A.; Kempton, T.; Ryan, S.; Forsyth, A.; Belski, R. Dietary intake of professional Australian football athletes surrounding body composition assessment. *J. Int. Soc. Sports Nutr.* **2018**, *15*, 43. [[CrossRef](#)] [[PubMed](#)]
30. Grams, L.; Garrido, G.; Villaceros, J.; Ferro, A. Marginal micronutrient intake in high-performance male wheelchair basketball players: A dietary evaluation and the effects of nutritional advice. *PLoS ONE* **2016**, *11*, e0157931. [[CrossRef](#)] [[PubMed](#)]
31. Bettonviel, A.E.O.; Brinkmans, N.Y.J.; Russcher, K.; Wardenaar, F.C.; Witard, O.C. Nutritional status and daytime pattern of protein intake on match, post-match, rest and training days in senior professional and youth elite soccer players. *Int. J. Sport Nutr. Exerc. Metab.* **2016**, *26*, 285–293. [[CrossRef](#)]
32. Tooley, E.; Bitcon, M.; Briggs, M.A.; West, D.J.; Russell, M. Estimates of energy intake and expenditure in professional rugby league players. *Int. J. Sports Sci. Coach.* **2015**, *10*, 551–560. [[CrossRef](#)]
33. Raizel, R.; da Mata Godois, A.; Coqueiro, A.Y.; Voltarelli, F.A.; Fett, C.A.; Tiraepgui, J.; de Paula Ravagnani, F.C.; de Faria Coelho-Ravagnani, C. Pre-season dietary intake of professional soccer players. *Nutr. Health* **2017**, *23*, 215–222. [[CrossRef](#)]
34. Jagim, A.R.; Zabriskie, H.; Currier, B.; Harty, P.S.; Stecker, R.; Kerksick, C.M. Nutrient status and perceptions of energy and macronutrient intake in a group of collegiate female lacrosse athletes. *J. Int. Soc. Sports Nutr.* **2019**, *16*, 43. [[CrossRef](#)] [[PubMed](#)]
35. Sukur, A.; Lubis, J.; Fitrianto, E.J.; Hartono, F.V.; Jauhari, M.; Nurulfa, R. Nutritional status and adequacy of disabled athletes from Indonesia. *Int. J. Phys. Educ. Sports Health* **2022**, *22*, 2939–2946.
36. Gershuni, V.M.; Yan, S.L.; Medici, V. Nutritional ketosis for weight management and reversal of metabolic syndrome. *Curr. Nutr. Rep.* **2018**, *7*, 97–106. [[CrossRef](#)]
37. Volek, J.S.; Sharman, M.J.; Love, D.M.; Avery, N.G.; Gomez, A.L.; Scheett, T.P.; Kraemer, W.J. Body composition and hormonal responses to a carbohydrate-restricted diet. *Metab. Clin. Exp.* **2002**, *51*, 864–870. [[CrossRef](#)]



38. Valsdottir, T.D.; Øvrebø, B.; Falck, T.M.; Litleskare, S.; Johansen, E.I.; Henriksen, C.; Jensen, J. Low-carbohydrate high-fat diet and exercise: Effect of a 10-week intervention on body composition and CVD risk factors in overweight and obese women—A randomized controlled trial. *Nutrients* **2021**, *13*, 110. [CrossRef]
39. Depeint, F.; Bruce, W.R.; Shangari, N.; Mehta, R.; O'Brien, P.J. Mitochondrial function and toxicity: Role of the B vitamin family on mitochondrial energy metabolism. *Chem. Biol. Interact.* **2006**, *163*, 94–112. [CrossRef]
40. Suwannasom, N.; Kao, I.; Pruß, A.; Georgieva, R.; Bäuml, H. Riboflavin: The health benefits of a forgotten natural vitamin. *Int. J. Mol. Sci.* **2020**, *21*, 950. [CrossRef]
41. Mascolo, E.; Verni, F. Vitamin B6 and diabetes: Relationship and molecular mechanisms. *Int. J. Mol. Sci.* **2020**, *21*, 3669. [CrossRef]
42. Boachie, J.; Adaikalakoteswari, A.; Samavat, J.; Saravanan, P. Low vitamin B12 and lipid metabolism: Evidence from pre-clinical and clinical studies. *Nutrients* **2020**, *12*, 1925. [CrossRef]
43. Li, Z.; Gueant-Rodriguez, R.-M.; Quilliot, D.; Sirveaux, M.-A.; Meyre, D.; Gueant, J.-L.; Brunaud, L. Folate and vitamin B12 status is associated with insulin resistance and metabolic syndrome in morbid obesity. *Clin. Nutr.* **2018**, *37*, 1700–1706. [CrossRef] [PubMed]
44. Młodzik-Czyżewska, M.A.; Malinowska, A.M.; Chmurzynska, A. Low folate intake and serum levels are associated with higher body mass index and abdominal fat accumulation: A case control study. *Nutr. J.* **2020**, *19*, 53. [CrossRef] [PubMed]
45. Ibrahim, G.R.; Shah, I.; Gariballa, S.; Yasin, J.; Barker, J.; Salman Ashraf, S. Significantly elevated levels of plasma nicotinamide, pyridoxal, and pyridoxamine phosphate levels in obese Emirati population: A cross-sectional study. *Molecules* **2020**, *25*, 3932. [CrossRef] [PubMed]
46. Fu, Y.; Zhu, Z.; Huang, Z.; He, R.; Zhang, Y.; Li, Y.; Tan, W.; Rong, S. Association between Vitamin B and obesity in middle-aged and older Chinese adults. *Nutrients* **2023**, *15*, 483. [CrossRef] [PubMed]
47. Wiebe, N.; Field, C.J.; Tonelli, M. A systematic review of the vitamin B12, folate and homocysteine triad across body mass index. *Obes. Rev.* **2018**, *19*, 1608–1618. [CrossRef] [PubMed]
48. Pourhoseingholi, M.A.; Vahedi, M.; Rahimzadeh, M. Sample size calculation in medical studies. *Gastroenterol. Hepatol. Bed Bench* **2013**, *6*, 14–27.
49. Dimitrijevic, M.; Paunovic, V.; Zivkovic, V.; Bolevich, S.; Jakovljevic, V. Body fat evaluation in male athletes from combat sports by comparing anthropometric, bioimpedance, and dual-energy X-ray absorptiometry measurements. *Biomed. Res. Int.* **2022**, *2022*, 3456958. [CrossRef]
50. Øvretveit, K. Anthropometric and physiological characteristics of Brazilian Jiu-Jitsu athletes. *J. Strength Cond. Res.* **2018**, *32*, 997–1004. [CrossRef]
51. Duren, D.L.; Sherwood, R.J.; Czerwinski, S.A.; Lee, M.; Choh, A.C.; Siervogel, R.M.; Chumlea, W.C. Body composition methods: Comparisons and interpretation. *J. Diabetes Sci. Technol.* **2008**, *2*, 1139–1146. [CrossRef]
52. Skerneckis, J.; Milasius, K.; Raslanas, A.; Dadelienė, R. Sporto treniruotė (Fitness Training). In *Athlete Skills and Training Them*, 1st ed.; Čepulėnas, A., Sapliński, J., Paulauskas, R., Eds.; Lithuanian University of Educational Sciences Press: Vilnius, Lithuania, 2011; pp. 165–217.
53. Pomerleau, J.; McKee, M.; Robertson, A.; Vaasc, S.; Kadziauskiene, K.; Abaravicius, A.; Bartkeviciute, R.; Pudule, I.; Grinberga, D. Physical inactivity in the Baltic countries. *Prev. Med.* **2000**, *31*, 665–672. [CrossRef] [PubMed]
54. Conway, J.M.; Ingwersen, L.A.; Vinyard, B.T.; Moshfegh, A.J. Effectiveness of the US Department of Agriculture 5-Step Multiple-Pass Method in Assessing Food Intake in Obese and Nonobese Women. *Am. J. Clin. Nutr.* **2003**, *77*, 1171–1178. [CrossRef] [PubMed]
55. Deakin, V.; Kerr, D.; Boushey, C. Measuring nutritional status of athletes: Clinical and research perspectives. In *Clinical Sports Nutrition*, 5th ed.; Burke, L.M., Deakin, V., Eds.; McGraw-Hill: North Ryde, Australia, 2015; pp. 27–53.
56. Jeoung, B.; Kim, J. Analysis and evaluation of nutritional intake and nutrition quotient of Korean athletes with disabilities in the Tokyo Paralympic games. *Nutrients* **2021**, *13*, 3631. [CrossRef] [PubMed]
57. Barzda, A.; Bartkevičiūtė, R.; Viseckienė, V.; Abaravičius, A.J.; Stukas, R. *Maisto Produktų ir Patiekalų Porcijų Nuotraukų Atlasas (Atlas of Foodstuffs and Dishes)*; Republican Nutrition Center Vilnius; Vilnius University Faculty of Medicine: Vilnius, Lithuania, 2007; pp. 7–42. Available online: [http://www.smlpc.lt/media/file/Skyriu\\_info/Metodine\\_medziaga/Maisto%20prod%20atlasas%202007.pdf](http://www.smlpc.lt/media/file/Skyriu_info/Metodine_medziaga/Maisto%20prod%20atlasas%202007.pdf) (accessed on 18 April 2020).
58. Erhardt, J. Nutrition Baseline Software. University of Indonesia. Available online: <http://www.nutrisurvey.de/> (accessed on 5 April 2018).
59. Sučilienė, S.; Abaravičius, A. *Food Product Composition*; Ministry of Health of the Republic of Lithuania: Vilnius, Lithuania, 2002; pp. 10–315.
60. Institute of Medicine (US) Subcommittee on Interpretation and Uses of Dietary Reference Intakes; Institute of Medicine (US) Standing Committee on the Scientific Evaluation of Dietary Reference Intakes. *Dietary Reference Intakes: Applications in Dietary Planning*; National Academies Press: Washington, DC, USA, 2003.
61. Harris, J.; Benedict, F. *A Biometric Study of Basal Metabolism in Man*; Lippincott: Philadelphia, PA, USA, 1919.
62. Ainsworth, B.E.; Haskell, W.L.; Herrmann, S.D.; Meckes, N.; Basset, D.R.; Todor-Locke, C.; Greer, J.L.; Vezina, J.; Whitt-Glover, M.C.; Leon, A.S. Compendium of physical activities: A second update of codes and MET values. *Med. Sci. Sports Exerc.* **2011**, *43*, 1575–1581. [CrossRef] [PubMed]



63. Kerksick, C.M.; Wilborn, C.D.; Roberts, M.D.; Smith-Ryan, A.; Kleiner, S.M.; Jäger, R.; Collins, R.; Cooke, M.; Davis, J.N.; Galvan, E.; et al. ISSN exercise & sports nutrition review update: Research & recommendations. *J. Int. Soc. Sports Nutr.* **2018**, *15*, 8.
64. Maughan, R.J.; Burke, L.M.; Dvorak, J.; Larson-Meyer, D.E.; Peeling, P.; Phillips, S.M.; Rawson, E.S.; Walsh, N.P.; Garthe, I.; Geyer, H.; et al. IOC consensus statement: Dietary supplements and the high-performance athlete. *Int. J. Sport. Nutr. Exerc. Metab.* **2018**, *28*, 104–125. [\[CrossRef\]](#)
65. Ministry of Health of the Republic of Lithuania. 2016 June 23 Order No. V-836 of Minister of Health of the Republic of Lithuania. *Recommended Daily Intake for Energy and Nutrients*. Available online: <https://www.e-tar.lt/portal/lt/legalAct/4bd890f0428011e6a8ae9e1795984391> (accessed on 14 June 2018).
66. Institute of Medicine (US) Food and Nutrition Board. What Are Dietary Reference Intakes? In *Dietary Reference Intakes: A Risk Assessment Model for Establishing Upper Intake Levels for Nutrients*; National Academies Press (US): Washington, DC, USA, 1998. Available online: <https://www.ncbi.nlm.nih.gov/books/NBK45182/> (accessed on 23 September 2022).
67. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*; Routledge Academic: New York, NY, USA, 1988.
68. Marquet, L.-A.; Brisswalter, J.; Louis, J.; Tiollier, E.; Burke, L.M.; Hawley, J.A.; Hausswirth, C. Enhanced endurance performance by periodization of carbohydrate intake: “Sleep Low” strategy. *Med. Sci. Sports Exerc.* **2016**, *48*, 663–672. [\[CrossRef\]](#)
69. Cochran, A.J.; Myslik, F.; MacInnis, M.J.; Percival, M.E.; Bishop, D.; Tarnopolsky, M.A.; Gibala, M.J. Manipulating carbohydrate availability between twice-daily sessions of high-intensity interval training over 2 weeks improves time-trial performance. *Int. J. Sport Nutr. Exerc. Metab.* **2015**, *25*, 463–470. [\[CrossRef\]](#)
70. Impey, S.G.; Hearris, M.A.; Hammond, K.M.; Bartlett, J.D.; Louis, J.; Close, G.L.; Morton, J.P. Fuel for the work required: A theoretical framework for carbohydrate periodization and the glycogen threshold hypothesis. *Sports Med.* **2018**, *48*, 1031–1048. [\[CrossRef\]](#)
71. Jeukendrup, A.E. Periodized nutrition for athletes. *Sports Med.* **2017**, *47*, 51–63. [\[CrossRef\]](#)
72. Mata, F.; Valenzuela, P.L.; Gimenez, J.; Tur, C.; Ferreria, D.; Domínguez, R.; Sanchez-Oliver, A.J.; Martínez Sanz, J.M. Carbohydrate availability and physical performance: Physiological overview and practical recommendations. *Nutrients* **2019**, *11*, 1084. [\[CrossRef\]](#) [\[PubMed\]](#)
73. Noakes, T.D. Physiological models to understand exercise fatigue and the adaptations that predict or enhance athletic performance. *Scand. J. Med. Sci. Sport.* **2000**, *10*, 123–145. [\[CrossRef\]](#)
74. Baranauskas, M.; Tubelis, L.; Stukas, R.; Švedas, E.; Samsonienė, L.; Karanauskienė, D. Some aspects of nutrition and moderate body weight reduction in Lithuanian Olympic Sport Centre female basketball players. *Balt. J. Sport Health Sci.* **2011**, *2*, 3–9. [\[CrossRef\]](#)
75. Zhang, J.; Chen, J.; Sui, X.; Drenowatz, C.; Wang, Q. Association between different types of exercise and intake of nutrients including carbohydrate, fat, protein, and B vitamins in young adults. *Nutrients* **2023**, *15*, 806. [\[CrossRef\]](#) [\[PubMed\]](#)
76. Stukas, R.; Pečiukonienė, M.; Kemerytė-Riaubienė, E.; Baškienė, V. Some aspects of fat metabolism in an athlete’s body. *Sport Sci.* **2009**, *2*, 44–49.
77. Fung, T.T.; Rimm, E.B.; Spiegelman, D.; Rifai, N.; Tofler, G.H.; Willett, W.C.; Hu, F.B. Association between dietary patterns and plasma biomarkers of obesity and cardiovascular disease risk. *Am. J. Clin. Nutr.* **2001**, *73*, 61–67. [\[CrossRef\]](#)
78. Rousseau, A.S.; Robin, S.; Roussel, A.M.; Ducros, V.; Margaritis, I. Plasma homocysteine is related to foliate intake but not training status. *Nutr. Metab. Cardiovasc. Dis.* **2005**, *15*, 125–133. [\[CrossRef\]](#)
79. De Bree, A.; Verschuren, W.M.; Blom, H.J.; Kromhout, D. Association between B vitamin intake and plasma homocysteine concentration in the general Dutch population aged 20–65 y. *Am. J. Clin. Nutr.* **2001**, *73*, 1027–1033. [\[CrossRef\]](#)
80. Han, L.; Liu, Y.; Wang, C.; Tang, L.; Feng, X.; Astell-Burt, T.; Wen, Q.; Duan, D.; Lu, N.; Xu, G.; et al. Determinants of hyperhomocysteinemia in healthy and hypertensive subjects: A population-based study and systematic review. *Clin. Nutr.* **2017**, *36*, 1215–1230. [\[CrossRef\]](#) [\[PubMed\]](#)
81. Kumar, A.; Palfrey, H.A.; Pathak, R.; Kadowitz, P.J.; Gettys, T.W.; Murthy, S.N. The metabolism and significance of homocysteine in nutrition and health. *Nutr. Metab.* **2017**, *14*, 78. [\[CrossRef\]](#)
82. Rudreshkumar, K.J.; Majumdar, V.; Nagaraja, D.; Christopher, R. Relevance of plasma levels of free homocysteine and methionine as risk predictors for ischemic stroke in the young. *Clin. Nutr.* **2018**, *37*, 1715–1721. [\[CrossRef\]](#) [\[PubMed\]](#)
83. Sechi, G.; Sechi, E.; Fois, C.; Kumar, N. Advances in clinical determinants and neurological manifestations of B vitamin deficiency in adults. *Nutr. Rev.* **2016**, *74*, 281–300. [\[CrossRef\]](#)
84. Tardy, A.L.; Pouteau, E.; Marquez, D.; Yilmaz, C.; Scholey, A. Vitamins and minerals for energy, fatigue and cognition: A narrative review of the biochemical and clinical evidence. *Nutrients* **2020**, *12*, 228. [\[CrossRef\]](#)
85. Mahabir, S.; Ettinger, S.; Johnson, L.; Baer, D.J.; Clevidence, B.A.; Hartman, T.J.; Taylor, P.R. Measures of adiposity and body fat distribution in relation to serum folate levels in postmenopausal women in a feeding study. *Eur. J. Clin. Nutr.* **2008**, *62*, 644–650. [\[CrossRef\]](#) [\[PubMed\]](#)
86. Gunanti, I.R.; Marks, G.C.; Al-Mamun, A.; Long, K.Z. Low serum vitamin B-12 and folate concentrations and low thiamin and riboflavin intakes are inversely associated with greater adiposity in Mexican American children. *J. Nutr.* **2014**, *144*, 2027–2033. [\[CrossRef\]](#)
87. Lee, M.-R.; Jung, S.M. Serum folate related to five measurements of obesity and high-sensitivity C-reactive protein in Korean adults. *Nutrients* **2022**, *14*, 3461. [\[CrossRef\]](#)

88. Woolf, K.; Hahn, N.L.; Christensen, M.M.; Carlson-Phillips, A.; Hansen, C.M. Nutrition assessment of B-vitamins in highly active and sedentary women. *Nutrients* **2017**, *9*, 329. [[CrossRef](#)] [[PubMed](#)]
89. Woolf, K.; Manore, M.M. B-vitamins and exercise: Does exercise alter requirements? *Int. J. Sport Nutr. Exerc. Metab.* **2006**, *16*, 453–484. [[CrossRef](#)]
90. Piquereau, J.; Boitard, S.E.; Ventura-Clapier, R.; Mericskay, M. Metabolic therapy of heart failure: Is there a future for B vitamins? *Int. J. Mol. Sci.* **2021**, *23*, 30. [[CrossRef](#)]
91. Wang, Z.; Pini, M.; Yao, T.; Zhou, Z.; Sun, C.; Fantuzzi, G.; Song, Z. Homocysteine suppresses lipolysis in adipocytes by activating the AMPK pathway. *Am. J. Physiol. Endocrinol. Metab.* **2011**, *301*, E703–E712. [[CrossRef](#)]
92. Chiang, E.-P.; Smith, D.E.; Selhub, J.; Dallal, G.; Wang, Y.-C.; Roubenoff, R. Inflammation causes tissue-specific depletion of vitamin B6. *Arthritis Res. Ther.* **2005**, *7*, R1254–R1262. [[CrossRef](#)] [[PubMed](#)]
93. Food and Nutrition Board IOM. Dietary Reference Intakes for Thiamin, Riboflavin, Niacin, Vitamin B6, Folate, Vitamin B12, Pantothenic Acid, Biotin, and Choline. In *The National Academies Collection: Reports Funded by National Institutes of Health*; National Academies Press: Washington, DC, USA, 1998.

**Disclaimer/Publisher’s Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.