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# NEW EPIDEMIC OF MALNUTRITION IN YOUNG SLOVENIAN ATHLETES

## NOVA EPIDEMIJA PODHRANJENOSTI MLADIH SLOVENSKIH ŠPORTNIKOV

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**ABSTRACT**

**Objective:** The syndrome of relative energy deficiency in sports (RED-S) is the result of a prolonged period of low energy availability in athletes and leads to the deterioration of health and physical performance. Our study aimed to investigate the prevalence of RED-S-related health and performance problems in young Slovenian athletes, comparing middle (14-17 years) with late (18-21 years) adolescents.

**Methods:** We analysd data of 118 young athletes (61 females, 57 males) who had nutritional assessments. Statistical analysis was carried out to determine the prevalence of RED-S-related problems. RED-S was diagnosed using the Relative Energy Deficiency Tool and the Sports Clinical Assessment Tool. Nutrition-related risk factors for RED-S were assessed with the use of a questionnaire and analysis of a three-day food diary.

**Results:** The majority of athletes had at least one RED-S-related health disorder. The number of health-related disorders was significantly higher in females 3.0 (0.2) compared to males 1.6 (0.2). It was also significantly higher in middle 2.6 (0.2) compared to 1.9 (0.3) late adolescents. Potential nutritional risk factors for RED-S were low carbohydrate intake, skipping meals before and after practice, a desire to lose weight, and a history of weight loss in the past year.

**Conclusion:** The prevalence of health-related RED-S disorders and performance problems in young athletes is concerning, and our study indicates that middle adolescents are more vulnerable to this than late adolescents. Our findings suggest that screening for RED-S symptoms and nutrition-related risk factors for RED-S should be included in regular medical examination of young athletes.

**Keywords:**
Relative energy deficiency in sport
Young athletes
Low energy availability
Nutritional risk

***IZVLEČEK***

***Namen:*** *Sindrom relativnega pomanjkanja energije v športu (RED-S) je posledica daljšega obdobja nizke energijske razpoložljivosti športnikov in vodi v poslabšanje zdravja in telesne zmogljivosti. Cilj študije je bil raziskati razširjenost težav, povezanih z RED-S, v reprezentativni populaciji mladih slovenskih športnikov tekmovalcev. Primerjali smo mladoletne športnike (14-17 let) s polnoletnimi (18-21 let).*

***Metode:*** *Analizirali smo zbirko podatkov za 118 mladih športnikov (61 žensk, 57 moških), ki so imeli prehransko obravnavo v okviru zdravstvenega pregleda. Opravljena je bila statistična analiza za določitev razširjenosti težav, povezanih z RED-S, v štirih podskupinah: mladoletnice, polnoletnice, mladoletniki in polnoletniki. RED-S je bil diagnosticiran z orodjema Relative Energy Deficiency Tool in Sports Clinical Assessment Tool. S prehrano povezani potencialni dejavniki tveganja za RED-S so bili ocenjeni s pomočjo vprašalnika in analize 3-dnevnega dnevnika prehrane.*

***Rezultati:*** *Večina športnikov je imela vsaj en zdravstveni problem, povezan z RED-S; le sedem športnikov zdravstvenih težav ni imelo. Število zdravstvenih težav je bilo pomembno večje pri športnicah: 3,0 (0,2) kot športnikih: 1,6 (0,2). Prav tako je bil bistveno višji pri mladoletnih: 2,6 (0,2) v primerjavi s polnoletnimi: 1,9 (0,3). S prehrano povezani potencialni dejavniki tveganja za RED-S so bili nizek vnos ogljikovih hidratov, izpuščanje obrokov pred vadbo in po njej, želja po izgubi telesne mase in zgodovina izgube telesne mase v zadnjem letu.*

***Sklepi:*** *Razširjenost z zdravjem povezanih problemov RED-S in težav s telesno aktivnostjo pri mladih športnikih je zaskrbljujoča. Naša študija kaže, da so mladoletni športniki ranljivejši od polnoletnih mladih športnikov. Naše ugotovitve kažejo, da je treba presejanje za RED-S in s prehrano povezanih dejavnikov tveganja za RED-S vključiti v redne zdravstvene preglede mladih športnikov.*

***Ključne besede:***
*sindrom relativnega energijskega pomanjkanja v športu*
*mladi športniki*
*nizka energijska razpoložljivost*
*prehransko tveganje*

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## 1 INTRODUCTION

Insufficient energy intake in athletes leads to physiological disorders, which may result in health issues (1). In 2014, the IOC group of experts defined relative energy deficiency syndrome in sport (RED-S) as impaired body functioning due to a relative energy deficit (2). RED-S can result from low-energy nutritional intake and/or excessive exercise. According to scientific data, it is assumed that the key pathophysiological mechanism of RED-S is insufficient energy availability (EA) to support bodily functions and maintain optimal health and performance during physical activity. Melin et al. proposed the concept of different energy availability (EA) for men and women according to their physiological and clinical characteristics (3). It is currently considered that EA<30 kcal/kg FFM/day represents the threshold below which unfavorable physiological changes likely occur in both genders. EA under this threshold may lead to physiological dysfunctions with serious health and performance consequences, and is termed as low EA (LEA) (3). We currently do not have specific cut-off values for LEA in young athletes (younger than 18 years). However, studies show that athletes with long-term LEA might develop nutritional deficiencies, chronic fatigue, and an increased risk for infectious diseases (3, 4). In addition, they can develop physiological alterations, affecting metabolic rate, protein synthesis, growth, and development, cardiovascular and emotional health, and gastrointestinal, endocrine, reproductive, skeletal, renal, and nervous systems disorders (2, 4–6). Psychological disorders can be either the cause or consequence of LEA (3, 5, 7).

Our recent study revealed that young athletes (14-21 years), in general, have more health-related symptoms of RED-S than elite athletes (above 21 years) (8). The period of adolescence is a critical period for athletes' physical development, including altered body composition, metabolic and hormonal fluctuations, maturation of organ systems, and establishment of nutrient stores, and thus RED-S-related health disorders should be considered very seriously with regard to this age group (9,10). In terms of nutrition, the period of adolescence is also a critical life period for establishing personal relationships with food (11, 12). RED-S is a medical disorder and it is therefore essential to detect and if possible, prevent its consequences as soon as possible. This requires good knowledge of RED-S causes and symptoms by an athlete's support team. As there is little information regarding the RED-S in young adolescent athletes, the main aim of our study was to explore nutrition-related risk factors for RED-S using exploratory factor analysis and to compare two age sub-groups of athletes (middle adolescents 14-17 years vs. late adolescents 18-21 years) to evaluate potential differences regarding the nutritional risks for RED-S.

## 2 METHODS

Our retrospective study targeted young Slovenian athletes (14-21 years) who had undergone comprehensive nutritional assessment between the years 2015 to 2020. The study was approved by the Commission for Medical Ethics of the Slovenian Ministry of Health (number 0120-21/2019/8).

### 2.1 Subjects

The research inclusion criteria were that athletes had a nutritional assessment as part of their sports' medical examination. We screened 150 athletes' records and 118 met the inclusion criteria, of whom 61 were female and 57 were male. Eighty-four (46 females, 38 males) were in the middle adolescent group (14-17 years), and 34 (15 females, 19 males) were in the late adolescent group (18-21 years).

### 2.2 Questionnaire

We have retrospectively analysed nutritional questionnaire which were completed by the athletes themselves and tailored to detect RED-S-related health disorders and performance problems. The questionnaire was divided into five parts. In the first part we enquired about medical conditions and medication intake. The second part included questions regarding nutritional status, the third part about eating habits, the fourth part was an assessment of athletics performance, and the fifth part included a standard three-day weighted nutritional diary, a physical activity diary, and a customized standard food frequency questionnaire (13).

### 2.3 Nutritional assessment

All the athletes underwent a nutritional assessment by a clinical dietitian (14), body composition measurement before practice using the bioimpedance method (Bodystat Quadscan 4000) and laboratory analysis. Data about previous medical conditions was collected from the medical records of athletes that were available during the nutritional assessment. Energy and nutrient intake were analysed using the Open Platform for Clinical Nutrition (OPKP, http://opkp.si). Exercise energy expenditure was estimated for individual days using a physical exercise diary. The corresponding MET value was added to each recorded activity, which was obtained from the compendium of physical activities (15, 16). Energy availability (EA) (17) was calculated for each day. The Cunningham equation was used for calculating resting metabolic rate (RMR) (18).

### 2.4 RED-S diagnosis

RED-S-related disorders were assessed using questionnaires, body composition measurements, and laboratory analysis (see the parameters in Table 2). Disordered eating was detected by assessing a nutritional diary, a food and meal

frequency questionnaire, and a nutritional assessment interview. We also obtained the growth histories in last year of the young athletes. If their height was two standard deviations or more below the mean for children of that sex and chronologic age, we defined them as athletes with growth disorder (19). After the nutritional examination, we used the RED-S CAT tool (20), to diagnose RED-S. Therefore, athletes with LEA and RED-S-related disorders were diagnosed with RED-S.

### 2.5 Nutrition-related risk factors for RED-S

One of purposes of this study was to find potential nutritional risk factors for RED-S (other than LEA). After receiving the questionnaires and three-day food diaries the intakes of energy, protein, carbohydrates, fats, dietary fibre, iron, and calcium were calculated. The amount of carbohydrates and proteins in meals 1-4 h before training, during training and 1h after practice was calculated and questions regarding weight loss and desire to lose weight were analysed.

### 2.6 Statistical analysis

The results are presented as means, with the standard deviations (SD) for parametric data. The prevalence was calculated as the number of participants above/below the threshold for each assessment, divided by the total number of participants who completed that assessment. The normality of the distribution was analysed using the Shapiro-Wilk test. For data that was not normally distributed we used the Mann-Whitney test to evaluate the statistical significance. We used a Cronbach's alpha level of $p \leq 0.05$ as a threshold to accept our hypothesis. For data analysis and statistics, we used the Python libraries NumPy, SciPy, and Pandas, and used the Seaborn library for visualizations.

## 3 RESULTS

The demographic data, anthropometric characteristics, presence of chronic illness, hours of training per week and type of sports are presented in Table 1.

**Table 1.** Anthropometric characteristics and disease states of athletes.

| | Middle adolescents (14-17 years) | | Late adolescents (18-21 years) | |
|---|---|---|---|---|
| | Female | Male | Female | Male |
| Average height [cm] | 167.8±5.6 | 176.4±12.6 | 168.6±5.9 | 179.1±7.1 |
| Average body mass [kg] | 57.5±10 | 65.8±13 | 58.1±8.3 | 74.3±8.7 |
| Average BMI [kg/cm$^2$] | 20.4±2.7 | 20.9±2.1 | 20.4±2.5 | 22.9±2.6 |
| Body fat [%] | 20.7±4.7 | 12.8±5.7 | 17.3±3.5 | 9.6±3.5 |
| FFMI [kg/cm$^2$] | 16.1±1.8 | 18.1±1.7 | 16.5±1.1 | 20.4±2.4 |
| Chronic illness [number of athletes] | Asthma (5), Chronic gastritis (4), Hashimoto thyroiditis (2), Atopic dermatitis (1) | | Asthma (5) Chronic gastritis (2) Gastro oesophageal reflux disease (1), Arterial hypertension (1), Atopic dermatitis (1) | |
| Hours training per week [h] | 16.9±0.6 | | 19.2±1.0 | |
| Type of sport [number of athletes] | **Anaerobic:** acrobatics (1), skiing (1), sprint (4), gymnastics (1), wild water kayak (1), climbing (1) **Aerobic:** long distance running (4), biathlon (3), road cycling (1), mountain biking (1), mountain running (2), rowing (6), cross country skiing (3), triathlon (2) **Aerobic-anaerobic:** heptathlon (1), middle distance running (4), badminton (1), hockey (3), basketball (2), football (14), Nordic combine (1), short and middle-distance swimming (20), dance (1), handball (1), figure skating (1), tennis (4) | | **Anaerobic:** skiing (1), snowboarding (1), triple jump (1) sprint (2), wild water kayak (4), climbing (2), ski jumping (4) **Aerobic:** long distance running (1), biathlon (4), rowing (2), cross country skiing (3), triathlon (1) **Aerobic-anaerobic:** heptathlon (1), Nordic combine (1), volleyball (1), short and middle-distance swimming (3), handball (1), tennis (1) | |

### 3.1 Prevalence of RED-S related problems

The detailed information on prevalence of RED-S-related health disorders and performance problems is available in Table 2.

Figure 1 presents the distribution of all RED-S-related problems. To inspect distributions in health, and performance-related problems separately, refer to Figure 2 and Figure 3 respectively. All figures indicate that middle female adolescents had the highest number of RED-S-related problems (health disorders and performance problems). In addition, the highest risk of developing RED-S was found in adolescent female athletes. Middle adolescents had 2.6 (0.2) health-related problems while late adolescents had 1.9 (0.3).

**Table 2.** Prevalence of RED-S-related health disorder.

| RED-S-related health disorders | Middle adolescents (14-17 years) | | | | | | Late adolescents (18-21 years) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Female | | | Male | | | Female | | | Male | | |
| | Y | N | Prev. | Y | N | Prev. | Y | N | Prev. | Y | N | Prev. |
| **Reproductive system** | | | | | | | | | | | | |
| Primary amenorrhea (F) | 3 | 43 | 6.5% | | | | 0 | 15 | 0% | | | |
| Secondary amenorrhea (F) | 13 | 33 | 28.2% | | | | 5 | 10 | 35.7% | | | |
| Other disorders (F) | 18 | 28 | 39.1% | | | | 5 | 10 | 33.3% | | | |
| Low testosterone (M) | | | | 1 | 37 | 2.6% | | | | 0 | 19 | 0% |
| **Immunological system** | | | | | | | | | | | | |
| Several viral infections | 22 | 24 | 47.8% | 15 | 23 | 39.5% | 5 | 10 | 33.3% | 4 | 15 | 21.1% |
| Lymphopenia | 1 | 28 | 3.4% | 1 | 18 | 5.2% | 1 | 10 | 9.1% | 0 | 12 | 0% |
| Leukopenia | 3 | 26 | 10.3% | 1 | 19 | 5% | 2 | 10 | 16.7% | 1 | 11 | 8.3% |
| **Skeletal system** | | | | | | | | | | | | |
| Stress fractures | 3 | 43 | 6.5% | 0 | 38 | 0% | 0 | 15 | 0% | 0 | 19 | 0% |
| Osteoporosis/Osteopenia | 3 | 43 | 6.5% | 0 | 38 | 0% | 0 | 15 | 0% | 0 | 19 | 0% |
| **Endocrine system** | | | | | | | | | | | | |
| T3<3.1 pmol/l | 0 | 7 | 0% | 0 | 3 | 0% | 0 | 2 | 0% | 0 | 1 | 0% |
| T4<12 pmol/l | 0 | 7 | 0% | 1 | 2 | 33.3% | 1 | 1 | 50% | 1 | 0 | 100% |
| Glucose<4 mmol/l | 1 | 18 | 5.2% | 0 | 16 | 0% | 1 | 7 | 12.5% | 1 | 10 | 9.1% |
| TSH < 0.5 mU/l | 0 | 9 | 0% | 0 | 5 | 0% | 0 | 2 | 0% | 0 | 1 | 0% |
| TSH>4.3 mU/l | 2 | 7 | 22.2% | 0 | 5 | 0% | 0 | 2 | 0% | 0 | 1 | 0% |
| **Haematological system** | | | | | | | | | | | | |
| Ferritin<30 µg/l | 7 | 21 | 25% | 3 | 16 | 15.8% | 2 | 7 | 22.2% | 1 | 11 | 8.3% |
| Iron<10µmol/l | 2 | 24 | 7.7% | 2 | 15 | 11.7% | 1 | 9 | 10% | 0 | 12 | 0% |
| Haemoglobin < 120 g/l | 0 | 30 | 0% | 0 | 20 | 0% | 0 | 12 | 0% | 0 | 12 | 0% |
| **Psychological disorders** | | | | | | | | | | | | |
| Eating disorders | 7 | 39 | 15.2% | 1 | 37 | 2.6% | 3 | 12 | 20% | 0 | 19 | 0% |
| Disordered eating | 30 | 16 | 65.2% | 12 | 21 | 44.7% | 7 | 8 | 46.7% | 7 | 12 | 36.8% |
| Psychological problems | 29 | 17 | 63.0% | 8 | 29 | 21.6% | 6 | 9 | 40% | 1 | 18 | 5.3% |
| **Cardiovascular system** | | | | | | | | | | | | |
| Cholesterol<4 mmol/l | 7 | 14 | 33.3% | 8 | 9 | 47.1% | 3 | 3 | 50% | 3 | 8 | 27.3% |
| Cholesterol >5.2 mmol/l | 1 | 20 | 4.8% | 0 | 17 | 0% | 2 | 4 | 33.3% | 2 | 9 | 18.2% |
| HDL-cholesterol<1.45 mmol/l | 2 | 6 | 25% | 3 | 6 | 33.3% | 1 | 2 | 33.3% | 0 | 2 | 0% |
| LDL-cholesterol>2.59 mmol/l | 3 | 5 | 37.5% | 4 | 6 | 40% | 1 | 2 | 33.3% | 1 | 1 | 50% |
| Triglycerides>2.62 mmol/l | 0 | 8 | 0% | 0 | 8 | 0% | 0 | 3 | 0% | 0 | 2 | 0% |
| **Gastrointestinal system** | | | | | | | | | | | | |
| Gastrointestinal disorders | 13 | 33 | 28.2% | 0 | 38 | 0% | 3 | 12 | 20% | 3 | 16 | 15.8% |
| Digestion disorders (gastritis, constipation, diarrhoea, gastroesophageal reflux) | 4 | 42 | 8.7% | 0 | 38 | 0% | 1 | 14 | 6.7% | 1 | 18 | 5.3% |

| RED-S-related health disorders | Middle adolescents (14-17 years) | | | | | | Late adolescents (18-21 years) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Female | | | Male | | | Female | | | Male | | |
| | Y | N | Prev. | Y | N | Prev. | Y | N | Prev. | Y | N | Prev. |
| **Growth and development disorders** | | | | | | | | | | | | |
| Growth disorders | 4 | 42 | 8.7% | 6 | 32 | 15.8% | 1 | 14 | 6.7% | 0 | 19 | 0% |
| **RED-S-related performance problems** | | | | | | | | | | | | |
| **Problems in training process** | | | | | | | | | | | | |
| Tiredness | 35 | 11 | 76.1% | 24 | 14 | 63.2% | 12 | 3 | 80% | 13 | 6 | 68.4% |
| Muscle cramps | 8 | 38 | 17.4% | 13 | 25 | 34.2% | 1 | 14 | 6.7% | 8 | 11 | 42.1% |
| Other problems (Concentration, coordination, strength…) | 33 | 13 | 71.7% | 21 | 17 | 55% | 10 | 5 | 66.7% | 12 | 7 | 63.2% |
| **Other problems** | | | | | | | | | | | | |
| Recurring injury | 13 | 33 | 28.2% | 3 | 35 | 7.9% | 1 | 14 | 6.7% | 5 | 14 | 26.3% |
| Maintaining focus | 18 | 28 | 39.1% | 5 | 33 | 13.2% | 2 | 13 | 13.3% | 0 | 19 | 0% |

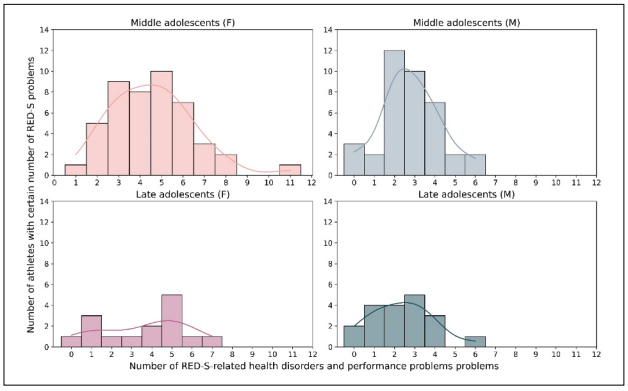


**Figure 1.** Distribution of number of RED-S-related health disorders and performance problems.

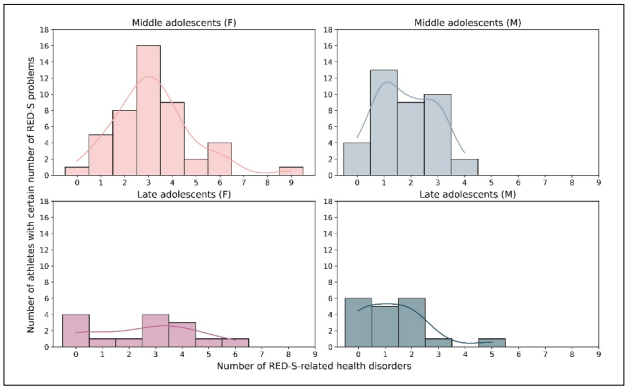


**Figure 2.** Distribution of number of RED-S-related health disorders.

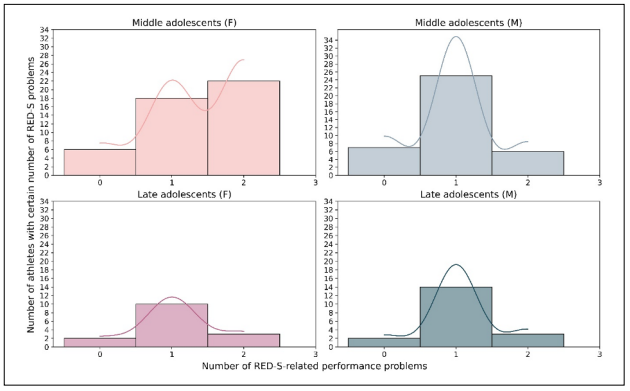


**Figure 3.** Distribution of number of RED-S-related performance problems.

### 3.2 Nutritional risk factors for RED-S

Clinical LEA (EA<30 kcal/kg FFM) was identified in 52.5% of middle female adolescents, 26.5% of middle male adolescents, 40% late female adolescents and 36.8% of late male adolescents. Subclinical LEA (female: 30 kcal/kg FFM<EA< 45kcal/kg FFM) was found in 28.3% female and 42.1% male middle adolescents and 40% female and 57.9% male late adolescents. In addition to identifying LEA, several potential nutritional risks for RED-S were detected, as presented in Table 3.

**Table 2.** Number of RED-S-related health disorders and performance problems in nutrition-related risk factors. Rows in the first column are the potential nutrition-related risk factors, and the numbers in the following columns are the numbers of RED-s related (with standard deviation) in athletes that have the particular nutritional risk (YES column) or don't have this risk (NO column).

| | All | | | Comparison by gender | | | | | | Comparison by age group | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Female | | | Male | | | Middle Adolescents (14-17 year) | | | Late Adolescents (18-21 year) | | |
| | Yes | No | p-value | Yes | No | p-value | Yes | No | p-value | Yes | No | p-value | Yes | No | p-value |
| **CHO< 3g/kg body mass** | 4.2±1.9 | 3.3±2.0 | 0.05 | 4.9±2.0 | 4.2±2.0 | 0.20 | 3.0±0.8 | 2.6±1.6 | 0.32 | 4.6±1.8 | 3.5±1.9 | 0.02 | 2.2±1.0 | 3.0±2.0 | 0.50 |
| **CHO<6g/kg body mass** | 3.6±2.0 | 3.2±1.9 | 0.32 | 4.4±2.0 | 3.9±2.1 | 0.43 | 2.6±1.3 | 2.8±1.8 | 0.51 | 4.0±2.0 | 3.1±1.7 | 0.09 | 2.8±1.7 | 3.2±2.5 | 0.70 |
| **Dietary fibre intake>35 g** | 4.0±2.1 | 3.5±1.9 | 0.40 | 4.5±2.2 | 4.3±2.0 | 0.76 | 2.7±1.5 | 2.6±1.5 | 0.90 | 4.6±1.8 | 3.7±1.9 | 0.17 | 2.3±2.3 | 3.0±1.9 | 0.58 |
| **LEA** | 3.5±2.0 | 3.7±1.8 | 0.45 | 4.4±2.1 | 4.0±1.9 | 0.48 | 2.4±1.3 | 3.5±1.7 | 0.03 | 3.9±2.0 | 3.5±1.7 | 0.56 | 2.6±1.8 | 5.0±1.8 | 0.03 |
| **Desire to lose body weight** | 4.6±1.8 | 3.3±1.9 | 0.002 | 5.8±1.4 | 4.0±2.0 | 0.006 | 3.5±1.4 | 2.4±1.4 | 0.02 | 5.2±1.8 | 2.4±1.4 | 0.003 | 3.8±1.7 | 2.7±1.9 | 0.13 |
| **Lost weight in past year** | 4.6±1.8 | 3.3±1.9 | 0.002 | 5.8±1.4 | 4.0±2.0 | 0.006 | 3.5 ± 1.4 | 2.4±1.4 | 0.02 | 5.2±1.8 | 2.4±1.4 | 0.003 | 3.8±1.7 | 2.7±1.9 | 0.13 |
| **Meal 2-3h before training** | 3.5±2.0 | 5.5±0.7 | 0.09 | 4.3±2.0 | 5.5±0.7 | 0.26 | 2.6 ± 1.5 | / | / | 2.8±1.9 | 5.0 | 0.19 | 3.7±1.9 | 6.0 | 0.25 |
| **Meal 1h before training** | 3.3±1.9 | 4.5±1.9 | 0.01 | 4.2±2.0 | 4.8±2.1 | 0.18 | 2.5 ± 1.5 | 3.7±1.3 | 0.03 | 3.5±1.9 | 4.9±1.7 | 0.005 | 2.9±1.9 | 2.8±1.9 | 0.96 |
| **Meal after training** | 3.4±2.0 | 4.5±0.9 | 0.05 | 4.3±2.1 | 4.5±0.6 | 0.84 | 2.5 ± 1.4 | 4.5±1.3 | 0.01 | 3.7±2.0 | 4.6±1.0 | 0.10 | 2.9±1.9 | 4.0 | 0.54 |
| **Have suitable meal before, during and after training** | 3.4±1.8 | 3.6±2.0 | 0.81 | 4.2±1.6 | 4.4±2.2 | 0.63 | 2.3± 1.5 | 2.7±1.5 | 0.40 | 3.5±2.0 | 3.8±1.9 | 0.46 | 3.2±1.4 | 2.8±2.1 | 0.47 |
| **Takes dietary supplements** | 3.6±2.0 | 3.3±1.9 | 0.48 | 4.5±2.1 | 4.0±1.9 | 0.38 | 2.6 ± 1.3 | 2.7±1.8 | 0.97 | 3.9±2.0 | 3.5±1.9 | 0.45 | 3.0±1.8 | 2.8±2.2 | 0.68 |

## 4 DISCUSSION

This retrospective analysis represents the first study on RED-S-related health disorders in the group of young Slovenian athletes using the IOC diagnostic tool RED-S CAT (20). Young athletes have always been presumed to be a healthy population. However, this study showed that they could easily compromise their health with their lifestyles. From a medical point of view, the results of our study are worrying, because as many as 87% of athletes in this population have at least one of the RED-S-related health disorders, and 85% have athletic performance-related problems. The reason is probably the athletes' high prevalence of clinical LEA (40%) and subclinical LEA (39%). In addition, middle adolescent athletes had a greater nutritional risk than late adolescents (p=0.02).

In comparison to the study of Rogers et al., we found that middle female adolescent athletes included in our study have more health-related disorders consistent with RED-S (92%) than the females in their study (80%) (Rogers et al., 2021). A similar range of health disorders is present in the male group, found in 82% of such athletes in our study. We did not find any data for young male athletes in the literature. Interestingly, the prevalence of RED-S health disorders in male athletes in our study is in the same range as in the female group in Rogers et al.'s study (21). However, the prevalence of LEA among athletes is comparable in both groups. In Logue et al. the clinical LEA was 22-58% (22), and in our previous study the prevalence was 40% (8). Similar results were found in middle adolescent endurance runners (14-17 years), as LEA was detected in 30% of males and 60% females (23). The prevalence in our study was high, at 52.5% in females and 36.8% in males.

We also identified some potential nutritional risk factors for RED-S that should be investigated in the prospective cohort studies as potential risk factors for this condition. In the middle adolescent group nutritional risk factors are low carbohydrate (CHO) intake below 3g/kg/day and skipping meals 1-3 hours before and one hour after practice (Table 3). Additional nutritional risk factors are the desire to lose weight and history of weight loss in the past year. CHO intake lower than 6-10 g/kg/day for athletes exercising moderately to high intensity (24) is commonly

reported in athletes with LEA (25, 26). We observed that athletes in the middle adolescent group with a CHO intake below 3g/kg/day have more RED-S-related health disorders than late adolescents (p=0.02). The results in Table 3 also showed that middle female adolescents often struggle with body weight and image issues, even through they are not yet elite athletes (11). The desire to lose body weight and weight loss in the past year are significantly related to RED-S in this group of athletes, although it is very well known that unsafe weight management practices can compromise athletic performance and negatively affect health (2). Athletes choose different strategies for losing weight: not eating, limiting energy or excluding food groups from the diet, engaging in pathological weight control behaviors and restricting fluids. These athletes often respond to pressures of the sport or activity, coaches, peers, or parents by adopting negative body images and unsafe practices to maintain an ideal body composition (28). We did not find any studies on skipping meals before, during and after practice and the prevalence of RED-S problems. Our study showed that athletes who skipped meals one hour before and one hour after practice had more RED-S problems.

None of the athletes included in our study were diagnosed with RED-S before our examination despite health or performance-related problems, most likely due to a lack of awareness of these health problems. This highlights an urgent need for systematic RED-S syndrome screening among adolescent athletes (14). However, establishing a diagnosis of RED-S can be challenging, as the symptoms can be subtle (2, 5, 20). A simple screening tool for RED-S syndrome would be of great help. The development, validation and implementation of such a tool remain tasks for the future in order to help decrease the prevalence of RED-S-related health disorders.

It should be noted that our study was retrospective and access to some laboratory analysis results and body composition data was limited. Because of the unavailability of indirect calorimetry, we did not assess metabolism-related disorders (such as low RMR). Moreover, the determination of menstrual dysfunction was based only on a self-reported questionnaire. We also did not use a validated questionnaire to assess disordered eating and eating disorders. Finally, we only had a small cohort of athletes training in aesthetic sports.

## 5 CONCLUSION

In conclusion, young athletes have always been considered as a healthy population. However, our study shows that young athletes are at risk of easily compromising their health when their nutritional strategy and energy availability is insufficient. From a clinical point of view, the results of our study are concerning, because as many as 87% of athletes in this population have at least one of the RED-S-related health disorders, and 85% have athletic performance-related problems. In addition, middle adolescents have a greater nutritional risk than late adolescents.

Our study clearly indicates that nutritional screening, examination, and treatment for young athletes should already start in early adolescence, as this population of athletes is most at risk of developing RED-S-related health disorders, which are expected to influence their development and future sports performance. We urgently need a simple nutritional screening tool to identify athletes at risk of developing – or who have already developed – RED-S.

## CONFLICTS OF INTEREST

None declared.

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## ETHICAL APPROVAL

The study was approved by the Commission for Medical Ethics of the Slovenian Ministry of Health (number 0120-21/2019/8).

## AVAILABILITY OF DATA AND MATERIALS

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

## REFERENCES

1. IOC consensus statement on sports nutrition 2010. J Sports Sci. 2011;29 Suppl 1:S3-4. doi: 10.1080/02640414.2011.619349.
2. Mountjoy M, Sundgot-Borgen J, Burke L, Carter S, Constantini N, Lebrun C, Meyer N, Sherman R, et al. The IOC consensus statement: Beyond the female athlete triad--Relative Energy Deficiency in Sport (RED-S). Br J Sports Med. 2014;48(7):491-497. doi: 10.1136/bjsports-2014-093502.

3. Melin AK, Heikura IA, Tenforde A, Mountjoy M. Energy availability in athletics: Health, performance, and physique. Int J Sport Nutr Exerc Metab. 2019;29(2):152-164. doi: 10.1123/ijsnem.2018-0201.
4. Nattiv A, Loucks AB, Manore MM, Sanborn CF, Sundgot-Borgen J, Warren MP, American College of Sports Medicine. American College of Sports Medicine position stand. The female athlete triad. Med Sci Sports Exerc. 2007;39(10):1867-1882. doi: 10.1249/mss.0b013e318149f111.
5. Mountjoy M, Sundgot-Borgen JK, Burke LM, Ackerman KE, Blauwet C, Constantini, et al. IOC consensus statement on Relative Energy Deficiency in Sport (RED-S): 2018 update. Br J Sports Med. 2018;52(11):687-697. doi: 10.1136/bjsports-2018-099193.
6. Ackerman KE, Holtzman B, Cooper KM, Flynn EF, Bruinvels G, Tenforde AS, et al. Low energy availability surrogates correlate with health and performance consequences of Relative Energy Deficiency in Sport. Br J Sports Med. 2019;53(10):628-633. doi: 10.1136/bjsports-2017-098958.
7. Stice E, South K, Shaw H. Future directions in etiologic, prevention, and treatment research for eating disorders. J Clin Child Adolesc Psychol. 2012;41(6):845-855. doi: 10.1080/15374416.2012.728156.
8. Peklaj E, Reščič N, Koroušic Seljak B, Rotovnik Kozjek N. Is RED-S in athletes just another face of malnutrition? Clin Nutr ESPEN. 2022;48:298-307. doi: 10.1016/j.clnesp.2022.01.031.
9. Baxter-Jones AD, Faulkner RA, Forwood MR, Mirwald RL, Bailey DA. Bone mineral accrual from 8 to 30 years of age: an estimation of peak bone mass. J Bone Miner Res. 2011;26(8):1729-1739. doi: 10.1002/jbmr.412.
10. Sawyer SM, Afifi RA, Bearinger LH, Blakemore SJ, Dick B, Ezeh AC, et al. Adolescence: A foundation for future health. Lancet. 2012;28;379(9826):1630-1640. doi: 10.1016/S0140-6736(12)60072-5.
11. Werner A, Thiel A, Schneider S, Mayer J, Giel KE, Zipfel S. Weight-control behaviour and weight-concerns in young elite athletes - a systematic review. J Eat Disord. 2013;30;1:18. doi: 10.1186/2050-2974-1-18.
12. Desbrow B, McCormack J, Burke LM, Cox GR, Fallon K, Hislop M, et al. Sports dietitians Australia position statement: Sports nutrition for the adolescent athlete. Int J Sport Nutr Exerc Metab. 2014;24(5):570-584. doi: 10.1123/ijsnem.2014-0031.
13. Blaznik U, Gregorič M, Delfar N, Zaletel M, Lavtar D, Koroušić Seljak B, et al. Slovenian national food consumption survey on children (infants and toddlers). EFSA Supporting Publications. 2019;16(11). doi: 10.2903/sp.efsa.
14. Cederholm T, Barazzoni R, Austin P, Ballmer P, Biolo G, Bischoff SC, et al. ESPEN guidelines on definitions and terminology of clinical nutrition. Clin Nutr. 2017;36(1):49-64. doi: 10.1016/j.clnu.2016.09.004.
15. Ainsworth BE, Haskell WL, Herrmann SD, Meckes N, Bassett DR Jr, Tudor-Locke C, et al. 2011 compendium of physical activities: A second update of codes and MET values. Med Sci Sports Exerc. 2011;43(8):1575-1581. doi: 10.1249/MSS.0b013e31821ece12.
16. Butte NF, Watson KB, Ridley K, Zakeri IF, McMurray RG, Pfeiffer KA, et al. A youth compendium of physical activities: Activity codes and metabolic intensities. Med Sci Sports Exerc. 2018;50(2):246-256. doi: 10.1249/MSS.0000000000001430.
17. Loucks AB, Kiens B, Wright HH. Energy availability in athletes. J Sports Sci. 2011;29 Suppl 1:S7-S15. doi: 10.1080/02640414.2011.588958.
18. Cunningham JJ. Body composition as a determinant of energy expenditure: a synthetic review and a proposed general prediction equation. Am J Clin Nutr. 1991;54(6):963-969. doi: 10.1093/ajcn/54.6.963.
19. de Onis M, Onyango AW, Borghi E, Siyam A, Nishida C, Siekmann J. Development of a WHO growth reference for school-aged children and adolescents. Bull World Health Organ. 2007;85(9):660-667. doi: 10.2471/blt.07.043497.
20. Mountjoy M, Sundgot-Borgen J, Burke L, Carter S, Constantini N, Lebrun C, et al. The IOC relative energy deficiency in sport clinical assessment tool (RED-S CAT). Br J Sports Med. 2015;49(21):1354.
21. Rogers MA, Appaneal RN, Hughes D, Vlahovich N, Waddington G, Burke LM, et al. Prevalence of impaired physiological function consistent with relative energy deficiency in sport (RED-S): An Australian elite and pre-elite cohort. Br J Sports Med. 2021;55(1):38-45. doi: 10.1136/bjsports-2019-101517.
22. Logue D, Madigan SM, Delahunt E, Heinen M, Mc Donnell SJ, Corish CA. Low energy availability in athletes: A review of prevalence, dietary patterns, physiological health, and sports performance. Sports Med. 2018;48(1):73-96. doi: 10.1007/s40279-017-0790-3.
23. Matt SA, Barrack MT, Gray VB, Cotter JA, Van Loan MD, Rauh MJ, et al. Adolescent endurance runners exhibit suboptimal energy availability and intakes of key nutrients. J Am Nutr Assoc. 2022;41(6):551-558. doi: 10.1080/07315724.2021.1925994.
24. Thomas DT, Erdman KA, Burke LM. Position of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and athletic performance. J Acad Nutr Diet. 2016;116(3):501-528. doi: 10.1016/j.jand.2015.12.006.
25. Melin A, Tornberg ÅB, Skouby S, Møller SS, Faber J, Sundgot-Borgen J, et al. Low-energy density and high fiber intake are dietary concerns in female endurance athletes. Scand J Med Sci Sports. 2016;26(9):1060-1071. doi: 10.1111/sms.12516.
26. Viner RT, Berning J, Harris M, Meyer N. Energy availability and dietary patterns of elite cyclists with lower than normal bone mineral density. Med Sci Sports Exerc. 2017;46:560. doi: 10.1249/01.mss.0000495149.68024.90.
27. Werner A, Thiel A, Schneider S, Mayer J, Giel KE, Zipfel S. Weight-control behaviour and weight-concerns in young elite athletes - a systematic review. J Eat Disord. 2013;30;1:18. doi: 10.1186/2050-2974-1-18.
28. Turocy PS, DePalma BF, Horswill CA, Laquale KM, Martin TJ, Perry AC, et al. National athletic trainers' association position statement: Safe weight loss and maintenance practices in sport and exercise. J Athl Train. 2011;46(3):322-336. doi: 10.4085/1062-6050-46.3.322.