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# Energy availability during training camp is associated with signs of overreaching and changes in performance in young female cross-country skiers

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## Abstract

*Study aim*: The aim of this study was to evaluate if young female skiers meet their energy and macronutrient requirements, and how energy availability (EA) and macronutrient intake affects their performance during an intensive training camp.
*Material and methods*: 19 female cross-country skiers (age 16.7 ± 0.7) filled in 48-hour food and training logs during a 5-day training camp. Fasting concentrations of hemoglobin, leptin, triiodothyronine (T3), insulin, insulin-like growth factor 1 (IGF-1), and glucose were measured before (PRE) and after (POST) the camp. Blood lactate (LA), heart rate (HR) and rating of perceived exertion (RPE) from a submaximal treadmill running test, jump height from counter movement jump (CMJ), and power from a reactive jump test (RJ) were also measured PRE and POST.
*Results*: Mean EA was 40.3 ± 17.3 kcal · kgFFM$^{-1}$ · d$^{-1}$. 58% of the participants had suboptimal EA, 37% had low EA, and 53% had suboptimal carbohydrate intake. HR, HR/RPE ratio, LA/RPE ratio, CMJ, hemoglobin, leptin, T3, and insulin decreased from PRE to POST. RPE and glucose increased from PRE to POST. EA during the camp correlated with changes in LA ($r = 0.54$, $p = 0.018$), LA/RPE ($r = 0.65$, $p = 0.003$), and RJ ($r = 0.47$, $p = 0.043$).
*Conclusions*: Many athletes had difficulties in meeting their energy and carbohydrate requirements during a training camp. Furthermore, sufficient EA may help to avoid overreaching and to maintain performance during an intensive training period.

**Key words: Carbohydrate – Female athlete – Macronutrient – Nutrition – Performance**

## Introduction

Cross-country (XC) skiing is a demanding sport that requires excellent aerobic and anaerobic capacities, adequate strength and ski-specific power, well-developed skiing technique, and the ability to attain and maintain high speeds [33]. To meet these demands, high and variable training loads are needed, which may, in turn, cause substantial challenges in optimizing energy and macronutrient intake, that are known to be among the key components when aiming to augment athletes´ performance, recovery, training adaptations, and health [39].

In XC skiing, low body weight may be an advantage on hilly courses and in poor gliding conditions, which may lead some skiers to restrict their eating in order to lose weight [29]. Combined with the high energy requirements of XC ski training [33, 35], weight control practises may lead to low energy availability (LEA) [31]. Long-term LEA, in turn, may lead to the so-called syndrome of Relative Energy Deficiency in Sport (RED-S) that can have detrimental effects on an athlete's performance and overall health [30]. Especially teenage female athletes may be at a higher risk for the negative health effects of RED-S, such as hormonal dysfunction, impairment of bone health, and increased risk of stress fractures [32]. Regrettably, little is known about the incidence of LEA related health problems among young female XC skiers.

Suboptimal energy and macronutrient intake during an intensive training period may decrease an athletes´ performance and impair recovery, ultimately leading to decreased training quality [39]. Furthermore, low EA and carbohydrate (CHO) intake have been suggested to increase the risk of illness, injury, and overreaching (OR, an

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accumulation of training and/or non-training stress resulting in short-term performance impairment), which, when not recognized, may lead to long-term impairment of athletic performance [25, 39]. There is no consensus regarding the early signs of OR, but changes in hormonal concentrations, vertical jump performance, heart rate (HR), blood lactate (LA), and rate of perceived exertion (RPE) have been reported after an overloading training period [6, 11, 16, 25, 38]. These changes may be severely compounded by inadequate energy and macronutrient intake, thus attention to nutrition may ultimately be an important factor for preventing the unnecessary negative effects of OR [25, 36].

Unfortunately, there is lack of sport-specific guidelines for energy and macronutrient intake for XC skiers, and thus more nutritional data collected from different training situations is required to provide specific recommendations to optimize XC skiers health, recovery, and performance, especially during high loads of training [8]. The aim of this study was to evaluate if young female XC skiers are meeting their individual energy requirements as well as the current recommendations for macronutrient intake for endurance athletes during a training camp, when the energy demand is high. Furthermore, we aimed to evaluate if EA and macronutrient intake during training camp is associated with training load induced changes in performance, and hormonal concentrations.

## Materials and methods

### Participants

Thirty-one (31) 15–17 year old female XC skiers from the Finnish Ski Associations´ under 18 year old national team were invited to join the study. Of those, a total of twenty-one (21) athletes were willing to participate. Two participants developed symptoms of respiratory infection before the first measurements, and thus the final number of participants was nineteen (19). Physical characteristics of the participants are presented in Table 1. The ethical board of the University of Jyväskylä approved the study and included procedures, and the study was conducted in accordance with the Declaration of Helsinki. All participants provided written informed consent to be involved in the study and were allowed to drop-out of the study at any time.

**Table 1.** Physical characteristics of the participants

| n =19 | Mean ± SD | Range |
|---|---|---|
| Age [years] | 16.7 ± 0.7 | 15.8–17.6 |
| Height [m] | 1.67 ± 0.4 | 1.62–1.74 |
| Weight [kg] | 59.9 ± 6.6 | 50.6–75.1 |
| Body Mass Index [kg · m$^{-2}$] | 21.5 ± 2.3 | 18.5–26.9 |
| Body Fat [%] | 15.9 ± 4.0 | 9.5–21.6 |

### Experimental overview

This cross-sectional observation study was carried out during a 5-day training camp at sea level in October. Participants filled in 48-hour food, training, and activity logs during the second and third day of the training camp. Anthropometric measurements and the Low Energy Availability in Females Questionnaire (LEAF-Q) [26] were completed the first morning of the training camp. Fasting blood samples and performance tests were carried out on the first (PRE) and the last morning (POST) of the training camp. The training program during the 96 hours between the measurements included 11–12 hours of training that consisted of 8.5–9.5 hours of low intensity training (target blood LA < 2 mmol · L$^{-1}$); 15–20 minutes of medium intensity training (target blood LA 2–4 mmol · L$^{-1}$); 35–50 minutes of high intensity training (target blood LA > 4 mmol · L$^{-1}$); and 100–110 minutes of speed, strength, and skill training.

### Anthropometric measurements

Anthropometric measurements were completed in the morning after 12 hours of fasting and a visit to the bathroom. Height of the participants was measured with a wall-mounted stadiometer. Body mass and body composition were measured following an overnight fast using bioimpedance (Inbody 720, Biospace Co., Seoul, Korea) measurement.

### Blood samples

Fasting blood samples were obtained from an antecubital vein for analysis of hemoglobin, cortisol, leptin, triiodothyronine (T3), insulin, insulin-like growth factor 1 (IGF-1), and glucose. PRE and POST samples from each subject were collected at the same time of day between 7am and 9am. Blood was drawn into EDTA tubes (Greiner-Bio-One GmbH, Kremsmünster, Austria) for analyses of hemoglobin that were completed immediately with Sysmex XP300 analyzer (SysmexCo., Kobe, Japan). For the determination of serum hormone concentrations, blood was drawn into Vacuette gel serum tubes (Greiner-Bio-One GmbH, Kremsmünster, Austria) and centrifuged at 3600 rpm for 10 min to collect serum, which was frozen at –20ºC. Concentrations of cortisol, leptin, T3, insulin, and IGF-1 were analyzed by an immunometric chemiluminescense method (Immulite 2000 XPi, Siemens Healthcare, United Kingdom). The assay sensitivities were 5.5 nmol · L$^{-1}$ (cortisol), 8.2 ug · L$^{-1}$ (leptin), 1.5 pmol · L$^{-1}$ (T3), 2 U · L$^{-1}$ (insulin), 1.7 nmol · L$^{-1}$ (IGF-1), and 2.0 mmol · L$^{-1}$ (glucose). Reliabilities expressed as a coefficient of variation

(CV) were 7.7% (cortisol), 4.9% (leptin), 8.1% (T3), 5.2% (insulin), 4.4% (IGF-1), and 5.5% (glucose).

**Performance tests**

Jump tests on a force plate (HUR FP8, Kokkola, Finland) and a submaximal treadmill running test were performed 90–180 min after morning measurements. Participants were instructed to eat a breakfast (not controlled) during the ~3 hours break between fasting measurements and the performance tests. After a 15 min warm-up that consisted of easy running outside at a self-selected submaximal speed participants performed a counter movement jump (CMJ) test. Participants were instructed to stand with feet shoulder-width apart and hands on hips while flexing the knees and trying to jump as high as possible. The best jump height of three attempts was calculated from impulse [20] using Coachtech system (Vuokatti Sports Technology Unit, University of Jyväskylä, Finland). For the reactive jump (RJ) participants were instructed to jump ten times in a row with straight knees and as high as possible with the shortest possible contact time. Only a small downward knee flexion after landing was allowed. Participants performed 2 x 10 jumps and the average power of the two best jumps from a single trial was calculated using equations by Bosco et al. (1983) [4]. It has been shown that both vertical jumps (e.g. CMJ) and continuous jumps (e.g. RJ) have been reported to be valid tests for determining explosive power [5].

A submaximal treadmill running test (4 × 4 min) was performed after the jump tests. Participants ran with a constant 10.0 km $\cdot$ h$^{-1}$ speed and the inclination was increased after each 4 min stage as follows: 0–4 min was 2%, 4–8min 4%, 8–12 min 7%, and 12–16 min 9%. Blood LA samples after each stage were obtained from the fingertip and collected into capillary tubes (20 μL), which were placed in a 1-mL hemolyzing solution and analyzed automatically after the completion of testing according to the manufacturer's instructions (EKF diagnostic, C-line system, Biosen, Germany). During the treadmill test, HR (Polar V800, Kempele, Finland) and RPE (Borg 6–20 scale [3]) were recorded from the final 15 seconds of each stage and values from the last stage were used in final analysis. HR/RPE and LA/RPE ratios were calculated. The test protocols described above were selected as they are the same that are generally used to monitor training status among Finnish XC skiers.

**Food, training and activity logs**

Participants filled in 48-hour food, training, and activity logs during the second and third day of the five-day training camp. During the training camp participants had three prescheduled meals in the restaurant of the local sport institute. Participants selected the contents of their meals from a buffet, and the energy and macronutrient contents of the dishes were obtained from the chef. Participants were allowed to have their own snacks between meals. Each participant recorded the timing, type and amount of foods and fluid consumed, quantifying intake using kitchen scales. Written and verbal instructions were given for accurate record keeping. In addition, a member of the research team took part to the meals to make sure that athletes were recording their food intake properly. A short recording period was selected to keep the subjects´ burden as small as possible.

The food logs were analysed for energy and macronutrient intake using Aivodiet-software (version 2.0.2.3, Mashie, Malmö, Sweden). Training logs were analysed for exercise energy expenditure (EEE) using equations by Charlot et al. (2014) [9]. The duration and average HR of each training session, participant body mass, and self-reported maximal oxygen uptake (the result from the most recent test completed at a sport institute), resting HR, and maximum HR were used for calculations. Total energy expenditure (TEE) was assessed from activity and training logs using MET values by Ainsworth et al. (2011) [1] and resting energy expenditure determined with the equation by Cunningham (1991) [12]. EA was estimated as EI minus EEE and expressed in kcal·kg fat-free mass (FFM)$^{-1}$ $\cdot$ day (d)$^{-1}$. EA was classified as low (<30 kcal $\cdot$ kgFFM$^{-1}$ $\cdot$ d$^{-1}$), moderate (30–45 kcal $\cdot$ kgFFM$^{-1}$ $\cdot$ d$^{-1}$), and optimal (>45 kcal $\cdot$ kgFFM$^{-1}$ $\cdot$ d$^{-1}$) according to cut-off values specified by Loucks et al. (2011) [22] Energy balance (EB) was calculated as TEE minus EI.

**Questionnaires**

Participants completed the Finnish version of LEAF-Q [26], which was used to assess the risk of low EA and prevalence of self-reported amenorrhea (absence of menstrual cycles for more than 90 d [31]). According to the Melin et al. (2014) a LEAF-Q-score of ≥8 indicates long-term energy deficiency risk [26].

**Statistical analysis**

Statistical analyses were conducted using SPSS Statistics 24 (IBM, Armonk, NY). Results are reported as means ± SD. Normality was assessed via Shapiro-Wilk. Differences between PRE and POST were analyzed either with a repeated-measures analysis of variance (normally distributed data) or Wilcoxon signed rank test (non-normally distributed data). Effect sizes were calculated as Cohen's *d* with threshold values of <0.2 (trivial), 0.2–0.5 (small), 0.5–0.8 (moderate), and >0.8 (large) [10]. Pearson's (normally distributed data) or Spearman's (non-normally distributed data) correlation coefficient were used to analyze correlations between variables. Statistical significance was defined as $p < 0.05$. Statistical trend was defined as $p < 0.100$.

## Results

The mean total score on the LEAF-Q was 6 ± 4. Five of the 19 athletes (26 %) had a total score of ≥8 and were therefore categorized as being at risk for a long-term energy deficiency. Since including these athletes to the total sample did not cause any major differences to the results, the analysis were done with the whole group. In figure 1 they have, however, been marked as triangles and a supplementary table 4 has been included to show the results without these five athletes. Three of the participants (16%) had self-reported secondary amenorrhea.

Table 2 summarizes the analysed variables from the food, training, and activity logs. Mean EI was similar with mean TEE indicating that athletes were in energy balance, although individual variation was high (–1349–2468 kcal · d$^{-1}$). Mean EA (40.3 ± 17.3 kcal · kgFFM$^{-1}$ · d$^{-1}$) was slightly below optimal level (>45 kcal · kgFFM$^{-1}$ · d$^{-1}$). Based on calculations from food logs seven athletes (37%) were classified as having LEA, four (21%) moderate EA, and eight (42%) had optimal EA during the training camp. All (100%) of the amenorrheic and four (25%) of the eumenorrheic athletes were categorized to have LEA during the training camp.

PRE and POST values from the performance and blood tests are presented in table 3. HR, HR/RPE, LA/RPE, and CMJ decreased while RPE increased from PRE to POST. Also statistical trends for the decrease of LA and RJ were detected. Hemoglobin, leptin, T3, and insulin decreased while glucose increased from PRE to POST. No changes in cortisol and IGF-1 were detected.

**Correlations**

EA correlated with PRE to POST changes in LA (r = 0.54, p = 0.018), LA/RPE (r = 0.65, p = 0.003,

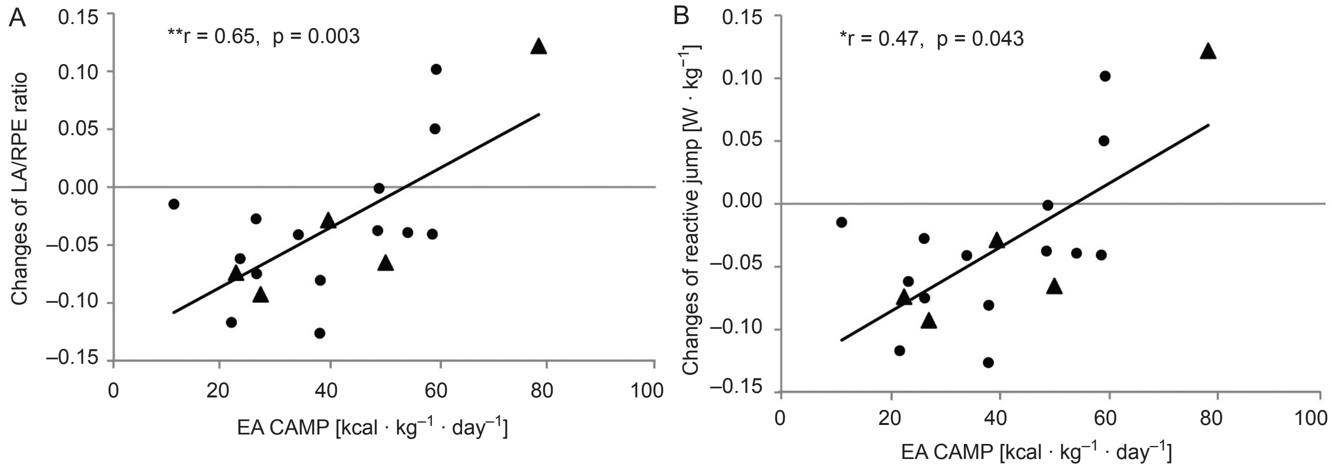


**Figure 1.** Associations of EA CAMP and PRE to POST changes of LA/RPE ratio (A) and reactive jump (B). Five athletes with LEAF-Q score ≥ 8 are marked with triangles. EA CAMP = energy availability during the training camp; PRE = performance tests before the training camp; POST = performance tests after the training camp; LA = blood lactate; RPE = rate of perceived exertion

**Table 2.** Mean (± SD) energy and macronutrient intake, energy expenditure, energy balance and energy availability during the training camp

| n = 19 | Mean ± SD | Range |
|---|---|---|
| Energy intake [kcal · d$^{-1}$] | 3653 ± 1057 | 2508–6274 |
| Total energy expenditure [kcal · d$^{-1}$] | 3548 ± 287 | 3041–4006 |
| Energy Balance [kcal · d$^{-1}$] | 106 ± 933 | –1349–2468 |
| Exercise energy expenditure [kcal · d$^{-1}$]) | 1591 ± 213 | 1147–1971 |
| Energy availability [kcal · kgFFM$^{-1}$ · d$^{-1}$] | 40.3 ± 17.3 | 11.1–78.4 |
| Carbohydrate intake [g · kg$^{-1}$ · d$^{-1}$] | 7.1 ± 1.6 | 4.5–9.4 |
| Protein intake [g · kg$^{-1}$ · d$^{-1}$] | 2.5 ± 0.5 | 1.6–3.5 |
| Fat intake [g · kg$^{-1}$ · d$^{-1}$] | 2.2 ± 0.8 | 1.2–4.3 |

**Table 3.** Mean (± SD) values from the last stage of the submaximal treadmill running test, force plate jumps, and blood analysis before the training camp (PRE) and after the training camp (POST)

| n = 19 | PRE | POST | p value | Effect size |
|---|---|---|---|---|
| Heart rate [bpm] | 189 ± 10 | 183 ± 10*** | < 0.001 | 1.51 |
| Lactate [mmol · $L^{-1}$] | 5.0 ± 1.6 | 4.6 ± 1.9 | 0.120 | 0.37 |
| RPE [6–20] | 15.8 ± 1.4 | 16.4 ± 1.3* | 0.030 | 0.54 |
| HR/RPE | 12.0 ± 1.0 | 11.2 ± 1.0** | 0.001 | 0.90 |
| LA/RPE | 0.31 ± 0.08 | 0.28 ± 0.08* | 0.041 | 0.52 |
| Counter movement jump [cm] | 32.0 ± 3.7 | 31.2 ± 3.2* | 0.036 | 0.52 |
| Reactive jump [W · $kg^{-1}$] | 44.6 ± 8.1 | 43.1 ± 8.0 | 0.065 | 0.45 |
| Hemoglobin [g · $L^{-1}$] | 145 ± 6 | 139 ± 5*** | < 0.001 | 1.50 |
| Cortisol [nmol · $L^{-1}$] | 506 ± 70 | 499 ± 49 | 0.586 | 0.13 |
| Leptin [ug · $L^{-1}$] | 31.6 ± 22.5 | 22.9 ± 13.6** | 0.004 | 0.61 |
| T3 [pmol · $L^{-1}$] | 5.5 ± 1.1 | 5.2 ± 0.7* | 0.020 | 0.59 |
| Insulin [U · $L^{-1}$] | 7.7 ± 4.5 | 5.9 ± 2.9* | 0.018 | 0.55 |
| IGF-1 [nmol · $L^{-1}$] | 40.7 ± 6.3 | 37.9 ± 7.1 | 0.086 | 0.42 |
| Glucose [mmol · $L^{-1}$] | 5.3 ± 0.3 | 5.5 ± 0.4* | 0.047 | 0.49 |

RPE = rate of perceived exertion; HR = heart rate; LA = blood lactate; T3 = triiodothyronine; IGF-1 = insulin-like growth factor 1. *p < 0.05, **p < 0.01, ***p < 0.001 significant difference between PRE and POST.

**Table 4.** Mean (± SD) values from the last stage of the submaximal treadmill running test, force plate jumps, and blood analysis before the training camp (PRE) and after the training camp (POST) when subjects with LEAF-Q score ≥ 8 have been excluded

| n = 14 | PRE | POST | p value | Effect size |
|---|---|---|---|---|
| Heart rate [bpm] | 187 ± 10 | 182 ± 11*** | < 0.001 | 1.29 |
| Lactate [mmol·$L^{-1}$] | 5.2 ± 1.7 | 4.8 ± 1.9 | 0.148 | 0.41 |
| RPE [6-20] | 16.1 ± 1.4 | 16.6 ± 1.3 | 0.058 | 0.49 |
| HR/RPE | 11.7 ± 0.8 | 11.0 ± 1.0* | 0.010 | 0.81 |
| LA/RPE | 0.32 ± 0.09 | 0.28 ± 0.10* | 0.046 | 0.59 |
| Counter movement jump [cm] | 32.7 ± 3.3 | 32.1 ± 2.7 | 0.157 | 0.40 |
| Reactive jump [W·$kg^{-1}$] | 45.5 ± 8.2 | 44.7 ± 7.8 | 0.065 | 0.25 |
| Hemoglobin [g·$L^{-1}$] | 144 ± 5 | 138 ± 5*** | < 0.001 | 1.87 |
| Cortisol [nmol·$L^{-1}$] | 504 ± 76 | 495 ± 52 | 0.581 | 0.15 |
| Leptin [ug·$L^{-1}$] | 37.1 ± 23.7 | 26.1 ± 13.6** | 0.009 | 0.69 |
| T3 [pmol·$L^{-1}$] | 5.6 ± 0.9 | 5.2 ± 0.7** | 0.005 | 0.88 |
| Insulin [U·$L^{-1}$] | 8.0 ± 5.1 | 5.8 ± 3.1* | 0.041 | 0.57 |
| IGF-1 [nmol·$L^{-1}$] | 40.6 ± 4.8 | 38.9 ± 6.3 | 0.080 | 0.51 |
| Glucose [mmol·$L^{-1}$] | 5.3 ± 0.3 | 5.5 ± 0.4* | 0.012 | 0.78 |

RPE = rate of perceived exertion; HR = heart rate; LA = blood lactate; T3 = triiodothyronine; IGF-1 = insulin-like growth factor 1. *p < 0.05, **p < 0.01, ***p < 0.001 significant difference between PRE and POST.

Figure 1A), and RJ ($r = 0.47$, $p = 0.043$, Figure 1B). There was also a positive trend between EA and changes of HR ($r = 0.38$, $p = 0.11$) and CMJ ($r = 0.42$, $p = 0.071$). CHO intake correlated with PRE to POST changes of RJ ($r = 0.48$, $p = 0.038$). No statistically significant correlations between blood parameter changes and nutrition were detected.

## Discussion

We aimed to evaluate if young female XC skiers meet their energy and macronutrient requirements and how EA and macronutrient intake affected their performance during an intensive training camp. Our results indicated that more than half of the young female XC skiers had suboptimal EA and CHO intake during a training camp. Lower EA and CHO intake were associated with signs of OR, including decreased muscular performance and submaximal LA/RPE ratio.

In the present study, 58% of young female XC skiers had suboptimal EA and negative EB during the training camp. Mean EI ($3653 \pm 1057$ kcal · $d^{-1}$) was similar to that reported among Swedish female elite XC skiers during training and sprint competition days at 3541–3643 kcal · $d^{-1}$ [8] but higher than the 2739–3142 kcal · $d^{-1}$ reported among Finnish 16–20 years old male and female endurance athletes including XC skiers [17]. Although mean EI was adequate to keep mean EB and mean EA near optimal values, individual variation was high. Ultimately, most (58%) of the athletes had suboptimal EA and seven (37%) athletes had LEA suggesting that most athletes did not achieve an adequate EI during the training camp. Even transient LEA may compromise performance, training quality, recovery, and training adaptation [34, 39]. Furthermore, if LEA persists for a long time, it may lead to RED-S associated health and performance problems, such as hormonal dysfunctions, menstrual disorders, and impaired bone health [30]. Taking these health and performance consequences in to account, it is concerning that over one third of the participants had LEA during the training camp. This finding indicates that it is essential to ensure that young athletes and their coaches understand the significance of sufficient EI during hard training periods.

According to the LEAF-Q five (26 %) athletes were considered to be at risk for long-term energy deficiency while incidence of self-reported current secondary amenorrhea was 16% ($n = 3$). Although these findings are somewhat more positive than the 50 % of self-reported amenorrhea detected in Finnish endurance runners [18], all (100%) of the amenorrheic athletes in the present study had LEA, while the incidence of LEA was lower (25%) among eumenorrheic participants. This supports the notion that LEA may be a risk factor for menstrual disorders [23, 30]. Although many studies have failed to find an association between menstrual disorders and real-world dietary EA at a group level [e.g. 18, 27], our findings suggest that food and training logs may be effective tools to help detect LEA and RED-S associated health and performance concerns when working with individuals.

According to current recommendations, endurance athletes should consume 6–10 g · $kg^{-1}$ · $d^{-1}$ CHO when training 1–3 h·$d^{-1}$ and 8–12 g · $kg^{-1}$ · $d^{-1}$ CHO when training 4–5 h · $d^{-1}$ [39]. Since the average training volume in the present study was between 3–4 h · $d^{-1}$ the amount of consumed CHO (~7 g · $kg^{-1}$ · $d^{-1}$) was at the lower end of the recommendations. At an individual level, many athletes (53%) consumed <7 g · $kg^{-1}$ · $d^{-1}$ CHO, which may be considered as the minimum recommendation for the current training volume. Suboptimal CHO intake among endurance athletes has been reported in many studies [e.g. 8, 17, 18] and may negatively impact XC skiing performance, training quality, immune function, and recovery [8, 33, 39]. In our study, lower CHO intake was associated with decreased muscular performance as the jump height in CMJ and power in RJ were impaired more in participants who had lower CHO intake during the training camp. Thus, adequate CHO intake should be emphasized and communicated to young athletes aiming to maximize their volume of high-quality training sessions while supporting their normal physiological growth and development [13].

As in previous studies [8, 17], we found that mean protein intake of young female XC skiers (2.5 g · $kg^{-1}$ · $d^{-1}$) exceeded the currently recommended level (1.2–2.0 g · $kg^{-1}$ · $d^{-1}$) for athletes [39]. Whole-body training [24] and high volume endurance training [19], may increase XC skiers´ protein needs compared to studies that have been used as a basis for the current recommendations [39]. Fat intake was within recommended 20–35% of total energy intake [39] in our study as well as in previous studies exploring XC skiers [8, 17]. Therefore, inadequate protein and fat intake does not seem to be major concern among female XC skiers, and more attention should be paid to ensure adequate CHO intake in these athletes, especially during intensive training periods.

There are several potential pathways through which LEA can lead to impaired sports performance [21, 30, 34]. In the present study, jump performance and submaximal HR, HR/RPE ratio and LA/RPE ratio decreased with increased training load, which could be interpreted to indicate that the recovery capacity of the athletes was exceeded. Although reduced submaximal HR and LA levels are traditionally considered to be a result of effective endurance training [15], short-term changes may also be an indicator of an increased level of fatigue or even OR after an intensive training period [16, 28, 36, 37]. Mean LA levels did not change significantly between PRE and POST but an association was observed between EA and LA changes.

Decreased LA response was associated with lower EA, which may be explained by depleted glycogen stores [36]. Furthermore, the observed decrease in the LA/RPE ratio was greater when EA was lower. While earlier studies have associated decreased LA/RPE ratio with OR [14, 37], our results show that the risk of OR may be greater when EA during intensified training period is insufficient. Although OR may be a natural and even desirable result of an intensified training period [25], our results support the idea that adequate EA may enable higher training intensity during the training camp and allow athletes to have higher overall training load before they need a recovery period.

Inadequate EA and CHO intake may negatively affect muscular performance. In line with the previous findings [2, 11], we detected that a training period with high load led to decreased vertical jump performance. Interestingly, a greater decrease of RJ was associated with lower EA and CHO intake and there was a negative trend between CMJ and EA. Although previous studies have reported decreased CMJ height after harder training [2, 11], this study gives novel information about how nutrition may also be related to decreases in jump performance. A recent study by Tornberg et al. (2017) [40] found that amenorrheic athletes had lower neuromuscular performance than eumenorreic athletes suggesting that long term LEA may decrease neuromuscular performance. Our results suggest that already short-term inadequate energy and CHO intake may compromise muscular performance. CHO is a key fuel for the brain and central nervous system [39] and thus diminished CHO stores may explain why jump performance decreased more in participants with lower EA and CHO intake. Since high speed and strength capacities are vital for success in today´s XC skiing [33], it is important that athletes have adequate energy and CHO availability to maintain muscular performance in key training sessions.

Both high training load and energy deficiency affect the endocrine system [25, 30]. We detected small but statistically significant decreases in mean hemoglobin, T3, insulin, and leptin from PRE to POST while resting glucose increased and cortisol remained unchanged. Although the mentioned decreases were statistically significant, their clinical significance may be minimal and these results should be interpreted with caution. Indeed, we did not find any significant associations between hormonal and nutritional variables and thus, intensified training may have affected the endocrine system more than nutrition status did.

The primary limitation of present study is accuracy of the methods used to assess energy intake, expenditure, and availability. Self-reported food logs typically underreport the nutritional intake of athletes [7], and HR based equations used in this study have not been validated in XC skiing and may have poor accuracy on an individual level [9]. In addition, measuring FFM with bioimpedance may have influenced EA values. Nevertheless, we used weighted food logs and athletes were highly motivated to get proper feedback on their nutrition and filled their logs as precisely as possible, which may have reduced bias related to misreporting. The second remarkable limitation was that we gathered nutrition and training data for only two days and thus made the assumption that athletes had similar nutritional intake throughout the training camp. Furthermore, including athletes with amenorrhea and LEAF-Q score ≥8 to the analysis may have influenced the results we observed during the camp (see minor influences in figure 1 and supplementary table 4). However, it is important to note that the study aim was to evaluate how EA and macronutrient intake affects performance during an intensive training camp regardless of the situation before the camp. Therefore, all of the athletes who followed the study protocol appropriately were included in analyses. Finally, our subject number and follow-up time were limited and we lacked a control group, which reduces the generalizability of the results. We acknowledge these short-comings in our work, but do want to emphasize the strengths of our study. Our research team took great care to continually interact with our participants throughout the study and to encourage their full and complete compliance with the standardized study protocols. Lastly, the athletes that participated did represent the best young female XC skiers in Finland and the association between EA and OR in the present population is a relatively exciting and novel finding which needs to be further investigated.

## Conclusions

It was shown that many young female XC skiers had suboptimal EA and CHO intake during an intensive training camp. Moreover, lower EA and CHO intake during this training camp were associated with the signs of OR and the deterioration of muscular performance as demonstrated by RJ and CMJ. Therefore, more attention should be paid to ensure that young female XC skiers meet their energy and macronutrient, particularly CHO, requirements to support performance and recovery. Finally, our results highlight the importance of young athletes and their coaches understanding the significance of sufficient EA and CHO intake for health and performance.

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