

Low energy availability status and screening indices in female Japanese collegiate athletes: A pilot study

ERINA MURAMATSU^{1*}, CHIKA OYA², KEISUKE TERAMOTO³

^{1,3} Aichi University of Education, Hirosawa 1, Igaya-cho, Kariya city, Aichi prefecture, JAPAN

² Aichi Shukutoku University, Katahira 2-9, Nagakute city, Aichi prefecture, JAPAN

Published online: June 30, 2026

Accepted for publication: June 15, 2026

DOI:10.7752/jpes.2026.06123

Abstract

Problem statement: Although the actual energy availability values have been measured in Japanese athletes, the measurement of low energy availability risk using alternative indicators that are easy to use on sports fields has not been sufficiently investigated in female Japanese athletes. **Purpose:** In this pilot study, we aimed to clarify the characteristics and related factors of female athletes at risk of low energy availability using the Low Energy Availability in Females Questionnaire and resting metabolism rate ratio, which are alternative methods for assessing the risk of low energy availability. **Approach:** Low Energy Availability in Females Questionnaire scores, energy availability, and resting metabolism rate were evaluated in 11 female Japanese college athletes to assess physiological symptoms of low energy availability. The resting metabolism rate ratio was calculated using the measured and estimated resting metabolism rate values. **Results:** Risk classification using the Low Energy Availability in Females Questionnaire score showed that energy availability was low in the risk group with a score ≥ 8 , and a low body fat percentage was observed in this group. Comparisons with the non-risk group allowed the identification of risk factors leading to low energy availability, such as high exercise energy expenditure. The low-resting metabolism rate ratio group showed low energy availability and high exercise energy expenditure, suggesting a relationship with risk factors. The body mass index and fat-free mass were higher in the low-resting metabolism rate ratio group than in the high-resting metabolism rate ratio group, suggesting that larger-bodied athletes may be at higher risk of low energy availability. **Conclusions:** The risk rate of low energy availability in our study was similar to that found in other countries, and female Japanese college athletes may commonly be at risk. In addition, body composition, high exercise energy expenditure, and carbohydrate intake per body weight may be associated with the risk of low energy availability. More studies are warranted to evaluate such risk in more participants.

Key Words: Low Energy Availability in Females Questionnaire, resting metabolism rate, energy availability, Japanese

Introduction

Low energy availability (LEA) in female athletes is an underlying cause of female athlete triad (FAT) along with amenorrhea and decreased bone mineral density (Mountjoy et al., 2023). LEA has various mental and physical effects, including decreased energy metabolism, immunity, and athletic performance, and increased risk of injury (Mountjoy et al., 2023). LEA takes a long time to recover from, making prevention important. Moreover, when EA falls below 30 kcal per kg of fat-free mass (FFM) unit, pulsed secretion of luteinizing hormone and follicle-stimulating hormone is inhibited by the pituitary gland, therefore 30 kcal per kg of FFM is indicated as the cutoff value for LEA (Loucks & Thuma, 2003). An energy availability (EA) below 30 kcal per kg of FFM for only 5 days can have serious endocrine and metabolic effects, such as reduced blood glucose and thyroid hormone (T3) levels (Loucks & Thuma, 2003). LEA, regardless of its duration, has negative effects on the bone (Papageorgiou et al., 2018). Subclinical EA corresponds to an EA between 30 and 45 kcal/kg of FFM (Melin et al., 2019). Thus, 45 kcal/kg of FFM are considered adequate EA levels and are recommended for maintaining all physiological functions and performance (Loucks & Thuma, 2003).

The early recognition and improvement of LEA can prevent the development of symptoms of relative energy deficiency in sport (RED-S). Gallant et al. (2025) recommended that coaches conduct regular surveys to identify athletes at risk of LEA. Therefore, to prevent LEA, and consequently FAT and RED-S, it is important to effectively and simply evaluate EA in actual sports environments. Logue et al. (2018) conducted EA evaluations in female athletes using different measurement methods, such as heart rate monitoring and dietary record. However, considering the difficulty of measuring actual EA on sports fields (Logue et al., 2020) and its burden on athletes, it remains difficult to assess LEA. Different studies (Heikura et al., 2018; Sim et al., 2021; Staal et al., 2018) have developed effective alternative indicators and screening methods to assess the risk of low EA. For example, simple risk assessment methods for LEA include indicators like the resting metabolic rate (RMR), which is a surrogate indicator for LEA (Staal et al., 2018). While similar, RMR is not fully synonymous to

BMR. BMR indicates the amount of energy required to maintain cells and tissues and to maintain a state of wakefulness and is measured under various conditions, such as immediately after awakening (Siedler et al., 2023). On the other hand, RMR can be measured at other times of the day and is considered to have greater clinical applicability (Siedler et al., 2023). However, RMR is influenced by various factors, and current guidelines (Academy of Nutrition and Dietetics, Evidence Analysis Library, 2014) recommend avoiding the consumption of stimulants like caffeine for 4 h before measurement, resting in the supine position for 30 min prior, and maintaining a quiet environment with no temperature fluctuations. The RMR is also decreased under conditions of chronic energy deficiency (Martin et al., 2007) and athletes with LEA and subclinical EA (< 45 kcal/kg FFM/day) have lower RMR per kg of FFM than those with sufficient EA (Melin et al., 2015). Moreover, lower RMR or RMR ratios have been reported to be valid surrogate indicators of LEA (De Souza et al., 2007; Sterringer et al., 2022). Questionnaire methods assessing risk from specific symptoms due to LEA are also increasingly used (Witkoś et al., 2023).

These methods are much simpler than the actual measurement of EA and are considered useful, motivating their dissemination to sports fields. In particular, the Low Energy Availability in Females Questionnaire (LEAF-Q) is broadly considered a useful approach for measuring FAT and RED-S, with a specificity of 90% and sensitivity of 78% (Melin et al., 2014). This method has been used in endurance athletes such as triathletes (Witkoś et al., 2023) and elite runners (Jesus et al., 2021), elite rock climbers (Monedero et al., 2023), footballers (Condo et al., 2019), and para-athletes (Pritchett et al., 2021). Furthermore, previous studies have reported LEA risk rates ranging from 33 % to 46 % (Folscher et al., 2015; Slater et al., 2016), and in other countries, the LEAF-Q has been used to clarify the actual LEA risk status. Although several studies have reported actual EA values measured in Japanese athletes (Goshozono et al., 2022; Taguchi et al., 2018; Watanabe et al., 2024), the measurement of LEA risk using alternative indicators that are easy to use on sports fields has not been sufficiently investigated in female Japanese athletes. In addition, the simplified assessment indicator-based actual risk rates have not been sufficiently clarified, and the characteristics of at-risk athletes and associated factors have not been identified. Therefore, clarifying the prevalence of LEA risk and its associated factors among Japanese female athletes is essential.

Furthermore, race affects resting metabolism and may influence fluctuations in absolute values and predicted values (Sterringer et al., 2022). Therefore, we deem a survey on the actual state of Asian and Japanese individual-specific LEA risk necessary. We believe it would be useful to focus on Asian and Japanese athletes using the alternative indicators LEAF-Q and RMR ratio to clarify the current risk status of LEA in this population and the characteristics and related factors of female athletes at risk. Therefore, in this pilot study, we aimed to clarify the characteristics and related factors of female athletes at risk of LEA using the LEAF-Q and RMR ratio, which are alternative methods for assessing the risk of LEA, in order to contribute to the reduction of the risk of energy deficiency in Japanese female athletes.

Materials and methods

Participants

Eleven Japanese female university athletes, including eight track and field athletes and three badminton athletes, participated in this cross-sectional study, with an age: 20.9 ± 1.3 years, height: 160.4 ± 6.5 cm, weight: 55.8 ± 9.7 kg, body mass index (BMI): 21.6 ± 2.9 kg/m², and competitive experience: 8.1 ± 4.0 years. The participants were determined to be trained/developmental to highly trained according to McKay et al. (2022). This research was conducted during the normal training period and was carried out from January to March 2023. The training frequency was 4.7 ± 0.5 times per week, and the weekly training time was 11.7 ± 2.8 h/week. Before the measurements, all study participants were fully informed about the purpose, methods, and risks of the study, and they provided written informed consent. The study was conducted in accordance with the Declaration of Helsinki and was approved by the ethics review board of Nippon Sport Science University in Japan (approval number, No. 015-H62).

Anthropometric and body composition measurements

Physical characteristics including height, weight, body composition (body fat percentage, body fat mass, and FFM), EA, LEAF-Q scores, and the RMR ratio were measured. Height was measured in units of 0.1 cm by using an analog height scale, and weight was measured in units of 0.1 kg. Body fat mass, body fat percentage, and FFM were measured using Inbody 430 (Inbody Japan Inc., Tokyo, Japan) for body composition. Inbody 430 is widely used in 70 countries and is a highly accurate and precise measurement method (Nakanishi et al., 2019).

Energy Availability and Exercise Energy Expenditure

EA was calculated using the following formula:

$$EA = (\text{Energy intake [kcal]} - \text{Exercise energy expenditure [kcal]}) / \text{FFM (kg)}$$

EA value is classified into LEA (less than 30 kcal/kg FFM/day) (Loucks & Thuma, 2003), subclinical LEA (30 kcal to 45 kcal/kg FFM/day) (Melin et al., 2019), and sufficient EA (more than 45 kcal/kg FFM/day) (Loucks & Thuma, 2003). In this study, it was classified into two groups: less than 30 kcal/kg FFM/day (risk group) and more than 30 kcal/kg FFM/day (non-risk group).

Exercise energy expenditure (EEE) was calculated using the Flex-HR method (Ceesay et al., 1989), which records the heart rate every minute using a heart rate monitor (Polar V800, H10; Polar Japan, Japan) during training and defines the boundary between resting and exercise. To determine the Flex-HR value and the HR-VO₂ relationship, an exercise stress test was conducted using an ergometer (828E; Monark Exercise AB, Vansbro, Sweden). The participants started exercise, and intensity was increased every 3 min by 30 W until exhaustion. During the exercise, VO₂ and VCO₂ were measured by indirect calorimetry through the breath-by-breath method using a breath gas analyzer (Aeromonitor AE-300S; Minato Medical & Scientific Corporation, Tokyo, Japan). The average value of the last minute of each stage was recorded.

The heart rate during exercise stress testing was recorded every minute using a heart rate monitor, and the value of the last minute of each stage was used. The subjective rate of perceived exertion (RPE) was confirmed verbally to the participant 1 minute before the end of each stage using the Borg Scale (6–20) (Borg et al., 1987). The end of the exercise test was determined when two or more of the following four conditions were met: RPE > 19; heart rate > 190 bpm; respiratory quotient > 1.10; and VO₂ reaching a plateau (Yoshida et al., 2015). The Flex-HR value was the average of the maximum heart rate recorded at rest (sitting or standing) and the minimum heart rate measured during exercise stress. When calculating EEE, if a heart rate below the Flex-HR value was recorded, the average energy expenditure measured at rest was uniformly inserted. For heart rates above the aforementioned values, EE was obtained from the HR-EE regression equation from individual exercise stress tests (Hikihara et al., 2005; Yoshida et al., 2015).

Dietary Energy Intake

Energy intake (EI) was measured for 3 days, including two training days and one off-training day, using a combination of the food record and photographic methods and nutrition information on food packages. All consumed foods were recorded as food portions and photographed using a smartphone by participants. The participants took photos of their meals with a ruler. If there was any remaining food, they took another photo after they had finished eating. The macronutrients were analyzed using nutritional analysis software (Healthy Maker Pro 501 software, Mushroom-soft, Okayama, Japan), which conformed to the Standard Tables of Food Composition in Japan, 2020. From these data, the daily EI, energy-producing nutrient intake ratio, protein intake per body weight, and carbohydrate intake per day were calculated.

LEAF-Q

The LEAF-Q includes questionnaire three sections on injury, gastrointestinal (GI) function, and menstrual function; a total score of 8 or higher is considered to indicate a risk for LEA (Melin et al., 2014). The LEAF-Q scores were used to divide the groups into the risk group (score ≥ 8) and the non-risk group (score < 8). A section score of > 2 for injuries, > 2 for GI function, and > 4 for menstrual dysfunction was considered to indicate “at risk” status for each subcategory (Henninger ET AL., 2024). By comparing the risk group and non-risk groups, we examined the relationship between risk and EA using the simplified assessment method or an alternative index to LEA.

RMR

The RMR was measured using the indirect calorimetry method, with participants coming to the laboratory early in the morning in a fasting state for at least 12 h. The participants were kept in a resting state in the supine position for 30 min (Fullmer ET AL., 2015) with their heart rate monitored (Polar V800, H10; Polar Japan, Japan) and wearing a gas collection mask. Subsequently, VO₂ and VCO₂ were measured in the supine position for 30 min (Silva et al., 2013) using a breath gas analyzer (Aeromonitor AE-300S; Minato Medical & Scientific Corporation, Tokyo, Japan) at 19.0–22.0°C. The RMR per day was calculated using Weir’s formula (Weir, 1949).

The RMR ratio was calculated with the following formula:

RMR ratio = mRMR/pRMR, where mRMR is the actual RMR and pRMR the estimated RMR calculated using Cunningham’s formula (Cunningham, 1980). This formula, which takes FFM under consideration, is a widely used formula.

Staal et al. (2018) used the cutoff value of 0.90 for a low RMR ratio. However, the cutoff value of 0.94 has been shown to be appropriate depending on the choice of the RMR prediction formula, and currently, there is no consensus regarding the use of prediction formulas or cutoff values. Additionally, cutoff values for Japanese individuals have not been clearly established. Therefore, in this study, the median (50th percentile, 0.95) of the RMR of the participants was used as the reference value, and the characteristics of the groups with high (n = 5) and low (n = 4) RMR ratios were analyzed.

Statistical Analysis

IBM SPSS Statistics Version 27 (IBM Japan, Tokyo, Japan) was used for statistical analyses. All data are presented as mean ± standard deviation. Shapiro–Wilk test was used to examine normality. Unpaired t-tests were used for group comparisons of items for which normality was found in EA, RMR ratio, and LEAF-Q, and Wilcoxon’s signed rank test was used when normality was not found in EA, RMR ratio, and LEAF-Q. The statistical significance level was set at $p \leq 0.05$. The relationships between groups by RMR ratio and LEAF-Q score were analyzed using Fisher’s exact test. The effect sizes were calculated using Cohen’s d and r (Cohen, 1988; Field, 2005). Cohen’s d was defined as a small (0.2–0.5), medium (0.5–0.8), or large (≥0.8) effect size. For r, 0.1–0.3, 0.3–0.5, and ≥0.5 were considered small, medium, and large effect sizes, respectively.

Results

Table 1 shows the overall and comparison results ($n = 11$) for the risk ($n = 4$, 36.4%) group including two track and field athletes and two badminton athletes and the non-risk group ($n = 7$, 63.6%) based on the LEAF-Q score. The overall LEAF-Q score was 5.4 ± 3.5 .

The body composition analysis showed that FFM (%) was $22.8 \pm 4.9\%$ in the non-risk group and $19.8 \pm 3.4\%$ in the risk group, with no significant difference but a moderate effect size, and a trend toward lower values in the risk group. For FFM, a small effect size suggested higher values for the risk group (45.1 ± 6.9 kg) than for the non-risk group (42.6 ± 47.1 kg). The risk group had a RMR per kg of FFM of 30.3 ± 2.7 , compared to 33.4 ± 3.2 for the non-risk group ($p = 0.073$, large effect size). In addition, the RMR ratio was 0.91 ± 0.05 in the risk group, which was significantly lower than the 0.98 ± 0.08 value in the non-risk group ($p < 0.05$, $r = -0.572$, large effect size). Then, the overall average EA was 34.3 ± 12.7 kcal/kg FFM/day. The EA in the risk group was 26.9 ± 10.2 kcal/kg FFM/day, compared to 38.5 ± 12.7 kcal/FFM/day in the non-risk group, which showed a trend toward lower values in the risk group ($p = 0.08$, $r = -0.456$, medium effect size).

The overall mean EA was 34.3 ± 12.7 kcal/kg FFM/day. There was also a trend toward lower EA values in the risk group: 26.9 ± 10.2 kcal/kg FFM/day ($p = 0.08$, medium effect size; non-risk group: 38.5 ± 12.7 kcal/kg FFM/day). The EEE was 862 ± 351 kcal in the risk group, which was significantly higher than the 565 ± 160 kcal in the non-risk group ($p < 0.05$, $d = -1.230$, large effect size). Energy intake was 2097 ± 551 kcal in the risk group and 2169 ± 369 kcal in the non-risk group, with no statistical difference ($p = 0.40$, $d = 0.165$). Meanwhile, carbohydrate intake per body weight showed a small effect size, but still no statistical difference ($p = 0.323$, $d = 0.299$), with the risk group having a lower intake.

The overall LEAF-Q score was 9.0 ± 0.8 points in the risk group, which was significantly higher than the 3.3 ± 2.5 points in the non-risk group ($p < 0.05$, $d = 2.730$, large effect size). The scores for each section showed a medium effect size in the injury and menstrual function sections in the risk group and a small effect size in the GI function section, indicating that the scores in the risk group tended to be higher. On the other hand, one athlete classified as belonging to the non-risk group had an EA value in the range of 30 kcal/kg FFM/day LEA, but was not classified as at risk by the LEAF-Q screening.

Table 1. Participant characteristics, energy expenditure, intake, and metabolism in groups based on LEAF-Q scores

Variable	All ($n=11$)	LEAF-Q score <8 ($n=7$)	LEAF-Q ≥ 8 ($n=4$)	p	Effect size	
Age (year)	20.9 $\pm$ 1.3	20.9 $\pm$ 1.4	20.8 $\pm$ 1.1	$p = 0.43$	0.114	-
Height (cm)	160.4 $\pm$ 6.5	159.1 $\pm$ 5.0	162.7 $\pm$ 9.0	$p = 0.21$	-0.541	M
Weight (kg)	55.8 $\pm$ 9.7	55.6 $\pm$ 11.5	56.0 $\pm$ 6.9	$p = 0.48$	-0.037	-
BMI (kg/m ²)	21.6 $\pm$ 2.9	21.8 $\pm$ 3.5	21.2 $\pm$ 1.8	$p = 0.37$	0.223	S
FM (%)	21.7 $\pm$ 4.5	22.8 $\pm$ 4.9	19.8 $\pm$ 3.4	$p = 0.15$	0.688	M
FM (kg)	12.3 $\pm$ 4.1	13.1 $\pm$ 5.0	11.0 $\pm$ 1.3	$p = 0.22$	0.503	M
FFM (kg)	43.5 $\pm$ 6.8	42.6 $\pm$ 7.1	45.1 $\pm$ 6.9	$p = 0.29$	-0.352	S
REE (kcal/day)	1389 $\pm$ 167	1408 $\pm$ 185	1356 $\pm$ 149	$p = 0.32$	0.303	S
REE/FFM (kcal/kg/day)	32.2 $\pm$ 3.3	33.4 $\pm$ 3.2	30.3 $\pm$ 2.7	$p = 0.07$	0.997	L
RMR _{ratio}	0.96 $\pm$ 0.08	0.98 $\pm$ 0.08	0.91 $\pm$ 0.05	$p < 0.05$	$r = -0.572$	L
EA (kcal/day)	34.3 $\pm$ 12.7	38.5 $\pm$ 12.7	26.9 $\pm$ 10.2	$p = 0.08$	$r = -0.456$	M
EEE (kcal/day)	673 $\pm$ 273	565 $\pm$ 160	862 $\pm$ 351	$p < 0.05$	-1.230	L
EI (kcal/day)	2143 $\pm$ 417	2169 $\pm$ 369	2097 $\pm$ 551	$p = 0.40$	0.165	S
Protein/weight (g/kg/day)	1.4 $\pm$ 0.3	1.4 $\pm$ 0.4	1.4 $\pm$ 0.2	$p = 0.50$	$r = -0.057$	-
Carbohydrate/weight (g/kg/day)	5.5 $\pm$ 0.8	5.5 $\pm$ 0.8	5.3 $\pm$ 1.0	$p = 0.32$	0.299	S
LEAF-Q score	5.4 $\pm$ 3.5	3.3 $\pm$ 2.5	9.0 $\pm$ 0.8	$p < 0.01$	2.730	L
Injury score	2.0 $\pm$ 2.6	1.1 $\pm$ 2.3	3.5 $\pm$ 2.9	$p = 0.16$	$r = -0.466$	M
Gastrointestinal score	1.7 $\pm$ 1.8	1.4 $\pm$ 1.4	2.3 $\pm$ 2.6	$p = 0.79$	$r = -0.117$	S
Menstrual score	1.6 $\pm$ 2.5	0.7 $\pm$ 1.5	3.3 $\pm$ 3.4	$p = 0.16$	$r = -0.466$	M

Data are presented as mean $\pm$ SD. Effect size (S, small; M, middle; L, large)

BMI, body mass index; FM, fat mass; FFM, fat-free mass; REE, resting metabolic rate; RMR ratio, the ration between the predicted and measured RMR using the Cunningham equation; EA, energy availability; EEE, exercise energy expenditure; EI, energy intake; LEAF-Q, low energy availability in females questionnaire

Table 2 shows the comparison between the two groups based on the median (50thile) RMR ratio (0.95). With the exception of the two participants whose RMR ratio was at the median, the nine participants were divided into a group with a low RMR ratio ($n = 4$, including two track and field athletes and two badminton athletes) and a group with a high RMR ratio ($n = 5$, including four track and field athletes and one badminton athlete).

The FFM showed a larger effect size in the low-RMR ratio group compared to that in the high-RMR ratio group ($p = 0.069$, $d = -1.122$). The BMI also showed a larger effect size ($p = 0.133$, $d = -0.812$), suggesting that the FFM and BMI in the low-RMR ratio group may be higher than those in the high-RMR ratio group. The RMR per 1 kg of FFM was 34.8 ± 2.6 kcal/kg/day in the high-RMR ratio group and 29.1 ± 1.2 kcal/kg/day in the low-RMR ratio group ($p < 0.01$, $d = 2.693$, large effect size), indicating that the low-RMR ratio group had a significantly lower RMR. In addition, the RMR ratio was significantly lower in the low-RMR ratio group ($p < 0.01$, $r = -0.820$, large effect size).

Table 2. Participant characteristics, energy expenditure, intake and metabolism in groups based on RMR ratio

Variable	RMRratio > 0.95 (n=5)	RMR ratio < 0.95 (n=4)	p	Effect size	
Age (year)	20.6 ± 1.2	21.8 ± 1.3	p = 0.09	1.003	L
Height (cm)	158.2 ± 4.0	160.3 ± 6.3	p = 0.28	0.407	S
Weight (kg)	52.5 ± 9.0	60.4 ± 11.1	p = 0.14	0.796	M
BMI (kg/m ²)	20.9 ± 3.2	23.3 ± 2.5	p = 0.13	-0.812	L
FM (%)	22.3 ± 5.5	21.4 ± 4.3	p = 0.40	0.181	-
FM (kg)	12.0 ± 4.5	13.2 ± 5.1	p = 0.35	-0.265	S
FFM (kg)	40.5 ± 5.6	47.2 ± 6.3	p = 0.07	-1.122	L
REE (kcal/day)	1405 ± 193	1371 ± 155	p = 0.39	0.191	-
REE/FFM (kcal/kg/day)	34.8 ± 2.6	29.1 ± 1.2	p < 0.01	2.693	L
RMR _{ratio}	1.01 ± 0.08	0.89 ± 0.03	p < 0.01	r = -0.820	L
EA (kcal/day)	39.6 ± 15.3	29.2 ± 8.8	p = 0.21	r = -0.327	M
EEE (kcal/day)	537 ± 166	859 ± 367	p = 0.06	-1.190	L
EI (kcal/day)	2098 ± 293	2239 ± 387	p = 0.28	-0.417	S
Protein/weight (g/kg/day)	1.4 ± 0.5	1.5 ± 0.1	p = 0.21	r = 0.327	M
Carbohydrate/weight (g/kg/day)	5.8 ± 0.7	5.1 ± 0.6	p = 0.08	1.046	L
LEAF-Q score	3.0 ± 2.6	6.5 ± 3.4	p < 0.05	1.323	L
Injury score	1.2 ± 2.7	2.3 ± 1.7	p = 0.41	r = -0.358	M
Gastrointestinal score	1.0 ± 1.0	3.3 ± 2.2	p = 0.11	r = -0.545	L
Mensutrial score	0.8 ± 1.8	1.0 ± 1.4	p = 0.73	r = -0.187	S

Data are presented as mean ± SD. Effect size (S, small; M, middle; L, large)

BMI, body mass index; FM, fat mass; FFM, fat-free mass; REE, resting metabolic rate; RMR ratio, the ration between the predicted and measured RMR using the Cunningham equation; EA, energy availability; EEE, exercise energy expenditure; EI, energy intake; LEAF-Q, low energy availability in females questionnaire

The group with low-RMR ratio had an EA of 29.2 ± 8.8 kcal/kg FFM/day which was as LEA and the group with high RMR ratio an EA of 39.6 ± 15.3 kcal/kg FFM/day which was as subclinical EA ($p = 0.206$), with a medium negative effect size ($r = -0.327$). Meanwhile, the EEE and EI, which are both components of EA, were 859 ± 367 kcal/day and 2239 ± 387 kcal/day in the group with low RMR ratio, respectively, and 537 ± 166 kcal/day and 2098 ± 293 kcal/day in the group with high RMR ratio. No significant differences were observed, but EEE showed a moderate effect size, while EI showed a small effect size, and both EEE and EI were higher in the low-RMR ratio group.

Furthermore, the protein intake per body weight showed a medium effect size, with the low-RMR ratio group (1.5 ± 0.1 g/kg/day) showing higher intake than the high-RMR ratio group (1.4 ± 0.5 g/kg/day). On the other hand, there was a trend toward lower carbohydrate intake in the low-RMR ratio group, with a difference between the low-RMR ratio group and the high-RMR ratio group ($p = 0.082$, $r = 1.046$).

The overall LEAF-Q score was significantly higher in the low-RMR ratio group (6.5 ± 3.4 points) than in the high-RMR ratio group (3.0 ± 2.6 points) ($p < 0.05$, $d = 1.323$, large effect size). The scores for each section showed a medium effect size for the injury section in the low-RMR ratio group, a large effect size for the GI function section, and a small effect size for the menstrual function section, with a trend toward higher scores for all items in the low-RMR ratio group.

Discussion

The risk group (score ≥ 8) based on the LEAF-Q score showed lower EA values than the non-risk group, and it was considered that the risk group might have higher EEE and lower body fat percentage and FFM. These results suggest that high energy expenditure due to high exercise volume and high FFM related to energy expenditure cause low EA, which results in low body fat mass and fat percentage and may be a characteristic of female athletes at risk for LEA. Additionally, the LEAF-Q score may not only help understand the physiological symptoms associated with LEA, but also suggest a potential association with its risk factors (LEA and low body fat percentage related to sex hormone secretion).

Furthermore, the low-RMR ratio group showed high FFM and BMI, consistent with previous studies. Ikegami et al. (2022) reported that athletes exhibiting LEA have high weight and body fat percentage. Body weight and EA have also shown inverse correlations in other studies (Klein et al., 2023; Magee et al., 2020). Furthermore, larger-bodied athletes may have difficulty meeting their energy requirements (Klein et al., 2023). In this study, the group with lower RMR also had LEA and high FFM and BMI. These results suggest that athletes with larger bodies and higher FFM may be more likely to be at risk for LEA, related physiological symptoms, and reduced metabolic rates. Conversely, other studies found no significant relationship between the RMR ratio and EA Moss

et al., 2021; Rogers et al., 2021). Thus, there are cases with no clear conclusion regarding the risk of energy deficiency and decreased metabolic rate. Based on this, Sterringer et al. (2022) suggested that some people do not show metabolic suppression during acute or mild EA decline. Therefore, in the future, both cross-sectional and longitudinal studies using LEAF-Q scores and the RMR ratio are warranted. It is also necessary to examine differences in the effects on LEAF-Q scores and the metabolic rate depending on the presence or absence of chronic LEA as well as changes over time. Additionally, the risk group showed a decline in the metabolic rate, with a low RMR per kg of FFM and a low RMR ratio; therefore, we considered that the LEAF-Q score could be related to the risk of a decreased metabolic rate. Furthermore, Staal et al. (2018) reported that female dancers who scored ≥ 8 points in the LEAF-Q and were in a state of energy deficiency had a low RMR ratio. Therefore, LEAF-Q may be used simultaneously to screen for decreases in the RMR ratio and EA. In this study, differences in the RMR ratio were also observed depending on whether there was a risk based on the LEAF-Q score. LEAF-Q may also be used to screen for decreased RMR ratio in Japanese female university athletes. In a physiological response to LEA, the hypothalamic–pituitary–thyroid axis adapts to reduce energy expenditure (Misra & Klibanski, 2014). In an intervention experiment wherein EA was adjusted to 10, 20, 30, or 45 kcal/kgFFM/day (Loucks & Thuma, 2003), the thyroid hormone T3 level decreased under the conditions of ≤ 30 kcal/kgFFM/day. In this study, the group at risk of LEA also had a low average EA under 30 kcal/kgFFM/day (26.9 kcal/kgFFM/day), suggesting that LEA may affect the endocrine system, such as T3 levels, possibly leading to a decreased metabolic rate. However, this cross-sectional pilot study did not include hormone levels, and further investigations including hormone levels are necessary.

Regarding nutritional intake, the two groups classified by RMR ratio in this study had average protein intakes per body weight that met the American College of Sports Medicine recommendation of 1.2–2.0 g/kg (Thomas et al., 2016). However, the amount of carbohydrate per body weight was not sufficient, with all groups averaging less than 6 g/kg, compared to the International Olympic Committee's recommendation of 6–10 g/kg for athletes performing 1–3 h per day of moderate-to-high intensity practice (Burke et al., 2011). No significant difference was found in the EI of Japanese female athletes with amenorrhea compared with that of female athletes with normal or irregular menstruation (Koshimizu et al., 2016). In this study, there was also no significant difference in EI between the two groups, and carbohydrate intake per body weight was insufficient. In a recent review, it was proposed that low carbohydrate intake may not only contribute to LEA, but also have independent health and performance consequences in athletes (Lodge et al., 2023). Koshimizu et al. (2016) indicated that LEA athletes need to be careful about their intake of staple foods. Therefore, while EEE is also a risk factor for LEA, if a risk for LEA or a decrease in the metabolic rate is observed, an EI-increasing intervention that focuses on carbohydrate intake may be necessary to improve LEA in cases where it is difficult to adjust exercise.

The average EA (34.3 kcal/kg FFM/day) in this study was similar to that reported in previous studies involving female Japanese athletes (30.1–33.9 kcal/kg FFM/day) (Goshozono et al., 2022; Taguchi et al., 2018). In Japanese studies, including this study, the average EA was between LEA and subclinical EA; however, a minimum of 45 kcal/kg FFM/day is currently considered sufficient for maintaining performance as an athlete, suggesting that the average EA of Japanese female athletes may be insufficient. Furthermore, the percentage of the risk group (score ≥ 8) classified according to the LEAF-Q score is 36.4 %, which was similar to the risk rates reported in other studies (33%–46%) (Folscher et al., 2015; Slater et al., 2016). Therefore, we believe that it is necessary to evaluate the risk of LEA using simple assessment methods that can be used in sports settings in Japan and to actively use this screening method to prevent FAT.

Limitations

The number of participants in this pilot study was small and possibly insufficient to examine effectiveness, warranting studies with more participants in the future. In addition, the participants were athletes of two different sports, and it will be necessary to evaluate the results based on the characteristics of each sport, such as sprint, endurance, and power sports. Furthermore, compared to Western diets, Japanese diets use different ingredients and cooking methods, often making them more complex, and the EI of athletes is often underestimated (Yoshida et al., 2012).⁵¹ In this study, discrepancies in EA evaluation may have occurred due to underestimation of EI. However, Kinoshita et al. (2021) demonstrated that it is impractical to use prepared meals to improve the accuracy of free-living athletes. Therefore, in this study, we tried to reduce the error by using the photograph method in addition to the food record method, which has been used for nutritional surveys of athletes. Moreover, we observed one LEA athlete with an EA < 30 kcal/kgFFM/day in the non-risk group, therefore LEAF-Q does not allow identifying all athletes at risk. Therefore, it may be necessary to conduct comprehensive risk assessments of LEA by considering indicators such as BMI, FFM, and metabolic indexes such as the RMR ratio. Further studies are needed to investigate potential applications to sports settings.

Finally, it is unclear whether the cutoff values for the LEAF-Q and RMR ratio directly apply to the Japanese population, since the RMR and body size differ between foreign and Japanese individuals. Sterringer et al. showed that race may affect the RMR and cause variability in measurements and estimates (Sterringer et al., 2022). Further research related to LEA risk that accounts for race, including the Japanese and Asian populations, is needed.

Conclusions

This study clarified the risk of LEA in Japanese female athletes using LEAF-Q scores and RMR ratios. The results showed that the risk rate was similar to that in other countries, and that it is not uncommon for female Japanese college athletes to be at risk. Risk classification using the LEAF-Q score showed that EA was low in the risk group with a score ≥ 8 , and a low body fat percentage was observed in this group. Comparisons to the non-risk group allowed the identification of risk factors leading to LEA, such as high exercise energy expenditure (EEE). The low-RMR ratio group showed low EA and high EEE, suggesting a relationship with risk factors. The body mass index and fat-free mass were higher in the low-RMR ratio group than in the high-RMR ratio group, suggesting that larger-bodied athletes may be at higher risk of LEA.

In addition, carbohydrate intake per body weight may be associated with the risk of LEA. In this study, we used the alternative indicators LEAF-Q and RMR ratio, the actual prevalence of LEA risk and the factors associated with it among Japanese female college student athletes, and demonstrated that factors such as high EEE, larger body size, and low carbohydrate intake might be associated with the risk of LEA. Our results would provide potentially useful information related to future LEA prevention strategies for female college student athletes. However, as this was a pilot study, future studies should aim at evaluating the risk in more participants by competitive level and sport category, and performing more detailed risk factor assessment. Moreover, coaches should conduct simplified, regular surveys to facilitate LEA risk monitoring and timely implementation of preventive interventions in real-world sports settings.

Acknowledgements

We appreciate the time and effort provided by our volunteers. We would like to thank Editage (www.editage.com) for English language editing.

Funding

This work was supported by the Japan Society for the Promotion of Science (Grant Number, JP 17K13209).

Authors' Contributions

Erina Muramatsu had primary responsibility for the final content. All authors revised the manuscript critically for important intellectual content. All authors conceived conceptualization, investigation, and drafted the manuscript. All authors read and approved the final manuscript.

Conflict of Interest

The authors have no conflicts of interest directly relevant to the content of this article.

Data Availability Statement

The datasets acquired and analyzed in this study contain a large amount of personal information about the participants. Therefore, they will be disclosed at the discretion of the corresponding author on reasonable request.

References

- Academy of Nutrition and Dietetics, Evidence Analysis Library. EE: measuring resting metabolic rate (RMR) in the healthy and non-critically ill guideline. 2014. Accessed February 2, 2025. <https://www.andeal.org/topic.cfm?menu=5299&cat=5217>.
- Borg, G., Hassmén, P., & Lagerström, M. (1987). Perceived exertion related to heart rate and blood lactate during arm and leg exercise. *European Journal of Applied Physiology and Occupational Physiology*, 56(6), 679–685. <https://doi.org/10.1007/BF00424810>
- Burke, L.M., Hawley, J.A., Wong, S.H.S. & Jeukendrup, A.E. (2011). Carbohydrates for training and competition. *Journal of Sports Sciences*, 29 (Supplement 1), S17-S27. <https://doi.org/10.1080/02640414.2011.585473>
- Ceesay, S.M., Prentice, A.M., Day, K.C., Murgatroyd, P.R., Goldberg, G.R., Scott, W. & Spurr, G.B. (1989). The use of heart rate monitoring in the estimation of energy expenditure: A validation study using indirect whole-body calorimetry. *British Journal of Nutrition*, 61(2), 175-186. <https://doi.org/10.1079/BJN19890107>
- Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*, 2nd ed. Lawrence Erlbaum.
- Condo, D., Lohman, R., Kelly, M. & Carr, A. (2019). Nutritional intake, sports nutrition knowledge and energy availability in female Australian rules football players. *Nutrients*, 11(5), 971. <https://doi.org/10.3390/nu11050971>
- Cunningham, J.J. (1980). A reanalysis of the factors influencing basal metabolic rate in normal adults. *American Journal of Clinical Nutrition*, 33(11), 2372-2374. <https://doi.org/10.1093/ajcn/33.11.2372>
- De Souza, M.J., Hontscharuk, R., Olmsted, M., Kerr, G. & Williams, N.I. (2007). Drive for thinness score is a proxy indicator of energy deficiency in exercising women. *Appetite*, 48(3), 359-367, <https://doi.org/10.1016/j.appet.2006.10.009>
- Field, A. (2005). *Discovering Statistics Using SPSS*, 2nd ed: Sage Publications.
- Folscher, L.L., Grant, C.C., Fletcher, L. & Janse Van Rensburg, D.C. (2015). Ultra-marathon athletes at risk for the female athlete triad. *Sports Medicine – Open*, 1(1), 29. <https://doi.org/10.1186/s40798-015-0027-7>

- Fullmer, S., Benson-Davies, S., Earthman, C.P., Frankenfield, D.C., Gradwell, E., Lee, P.S., Piemonte, T. & Trabulsi, J. (2015). Evidence analysis library review of best practices for performing indirect calorimetry in healthy and non-critically ill individuals. *Journal of the Academy of Nutrition and Dietetics*, 115(9), 1417-1446.e2, <https://doi.org/10.1016/j.jand.2015.04.003>.
- Gallant, T.L., Ong, L.F., Wong, L., Sparks, M., Wilson, E., Puglisi, J.L. & Gerriets, V.A. (2025). Low energy availability and relative energy deficiency in sport: A systematic review and meta-analysis. *Sports Medicine*, 55(2), 325-339, <https://doi.org/10.1007/s40279-024-02130-0>
- Goshozono, M., Taguchi, M., Namba, A. & Torii, S. (2022). Energy availability is not altered during the menstrual cycle in female collegiate athletes [in Japanese]. *The journal of Japanese Society of Clinical Sports Medicine*, 30, 96-103.
- Heikura, I.A., Uusitalo, A.L.T., Stellingwerff, T., Bergland, D., Mero, A.A. & Burke, L.M. (2018). Low energy availability is difficult to assess but outcomes have large impact on bone injury rates in elite distance athletes. *International Journal of Sport Nutrition and Exercise Metabolism*, 28(4), 403-411. <https://doi.org/10.1123/ijsnem.2017-0313>, PubMed: 29252050.
- Henninger, K., Pritchett, K., Brooke, N.K., & Dambacher, L. (2024). Low energy availability, disordered eating, exercise dependence, and fueling strategies in trail runners. *International Journal of Exercise Science*, 16(2), 1471-1486. <https://doi.org/10.70252/FFDK5934>
- Hikihara, Y., Saitoh, S. & Yoshitake, Y. (2005). Validity of methods to measure total energy expenditure of baseball players in Japanese high school [in Japanese]. *Japanese Journal of Physical Fitness and Sports Medicine*, 54(5), 363-372. <https://doi.org/10.7600/jspfs.54.363>.
- Ikegami, N., Samukawa, M., Sakamaki-Sunaga, M., Sugawara, M., Torashima, S., Ishida, T., Kasahara, S. & Tohyama, H. (2022). The influence of low energy availability on bone mineral density and trabecular bone microarchitecture of pubescent female athletes: A preliminary study. *International Journal of Environmental Research and Public Health*, 19(9), 5580. <https://doi.org/10.3390/ijerph19095580>
- Jesus, F., Castela, I., Silva, A.M., Branco, P.A. & Sousa, M. (2021). Risk of low energy availability among female and male elite runners competing at the 26th European Cross-Country Championships. *Nutrients*, 13(3), 873. <https://doi.org/10.3390/nu13030873>
- Kinoshita, N., Uchiyama, E., Ishikawa-Takata, K., Yamada, Y. & Okuyama, K. (2021). Association of energy availability with resting metabolic rates in competitive female teenage runners: A cross-sectional study. *Journal of the International Society of Sports Nutrition*, 18(1), 70. <https://doi.org/10.1186/s12970-021-00466-w>
- Klein, D.J., McClain, P., Montemorano, V. & Santacroce, A. (2023). Pre-season nutritional intake and prevalence of low energy availability in NCAA Division III collegiate swimmers. *Nutrients*, 15(13), 2827. <https://doi.org/10.3390/nu1513282>
- Koshimizu, T. (2016). Nutritional guidance for improving "energy deficiency" among obstetricians and gynecologists [in Japanese]. *Acta Obstetrica et Gynaecologica Japonica*, 68, 16-24.
- Lodge, M.T., Ward-Ritacco, C.L. & Melanson, K.J. (2023). Considerations of low carbohydrate availability (LCA) to relative energy deficiency in sport (RED-S) in female endurance athletes: A narrative review. *Nutrients*, 15(20), 4457. <https://doi.org/10.3390/nu15204457>
- Logue, D., Madigan, S.M., Delahunt, E., Heinen, M., Mc Donnell, S.J. & Corish, C.A. (2018). Low energy availability in athletes: A review of prevalence, dietary patterns, physiological health, and sports performance. *Sports Medicine*, 48(1), 73-96. <https://doi.org/10.1007/s40279-017-0790-3>
- Logue, D.M., Madigan, S.M., Melin, A., Delahunt, E., Heinen, M., Donnell, S.M. & Corish, C.A. (2020). Low energy availability in athletes 2020: An updated narrative review of prevalence, risk, within-day energy balance, knowledge, and impact on sports performance. *Nutrients*, 12(3), 835. <https://doi.org/10.3390/nu12030835>
- Loucks, A.B. & Thuma, J.R. (2003). Luteinizing hormone pulsatility is disrupted at a threshold of energy availability in regularly menstruating women. *Journal of Clinical Endocrinology and Metabolism*, 88(1), 297-311. <https://doi.org/10.1210/jc.2002-020369>
- Magee, M. K., Lockard, B. L., Zabriskie, H. A., Schaefer, A. Q., Luedke, J. A., Erickson, J. L., Jones, M. T., & Jagim, A. R. (2020). Prevalence of low energy availability in collegiate women soccer athletes. *Journal of Functional Morphology and Kinesiology*, 5(4), 96, <https://doi.org/10.3390/jfmk5040096>
- Martin, C. K., Heilbronn, L. K., de Jonge, L., DeLany, J. P., Volaufova, J., Anton, S. D., Redman, L. M., Smith, S. R., & Ravussin, E. (2007). Effect of calorie restriction on resting metabolic rate and spontaneous physical activity. *Obesity*, 15(12), 2964-2973. <https://doi.org/10.1038/oby.2007.354>
- McKay, A. K. A., Stellingwerff, T., Smith, E. S., Martin, D. T., Mujika, I., Goosey-Tolfrey, V. L., Sheppard, J., & Burke, L. M. (2022). Defining Training and Performance Caliber: A Participant Classification Framework. *International Journal of Sports Physiology and Performance*, 17(2), 317-331. <https://doi.org/10.1123/ijspp.2021-0451>
- Melin, A., Tornberg, A. B., Skouby, S., Faber, J., Ritz, C., Sjödin, A., & Sundgot-Borgen, J. (2014). The LEAF questionnaire: a screening tool for the identification of female athletes at risk for the female athlete

- triad. *British Journal of Sports Medicine*, 48(7), 540–545. <https://doi.org/10.1136/bjsports-2013-093240>
- Melin, A., Tornberg, Å. B., Skouby, S., Møller, S. S., Sundgot-Borgen, J., Faber, J., Sidemann, J. J., Aziz, M., & Sjødin, A. (2015). Energy availability and the female athlete triad in elite endurance athletes. *Scandinavian Journal of Medicine and Science in Sports*, 25(5), 610–622. <https://doi.org/10.1111/sms.12261>
- Melin, A.K., Heikura, I.A., Tenforde, A. & Mountjoy, M. (2019). Energy availability in athletics: Health, performance, and physique. *International Journal of Sport Nutrition and Exercise Metabolism*, 29(2), 152-164. <https://doi.org/10.1123/ijsnem.2018-0201>
- Misra, M. & Klibanski, A. (2014). Endocrine consequences of anorexia nervosa. *Lancet, Diabetes and Endocrinology*, 2(7), 581-592. [https://doi.org/10.1016/S2213-8587\(13\)70180-3](https://doi.org/10.1016/S2213-8587(13)70180-3)
- Monedero, J., Duff, C. & Egan, B. (2023). Dietary intakes and the risk of low energy availability in male and female advanced and elite rock climbers. *Journal of Strength and Conditioning Research*, 37(3), e8-e15. <https://doi.org/10.1519/JSC.0000000000004317>
- Moss, S.L., Randell, R.K., Burgess, D., Ridley, S., O'Caireallain, C., Allison, R. & Rollo, I. (2021). Assessment of energy availability and associated risk factors in professional female soccer players. *European Journal of Sport Science*, 21(6), 861-870. <https://doi.org/10.1080/17461391.2020.1788647>
- Mountjoy, M., Ackerman, K. E., Bailey, D. M., Burke, L. M., Constantini, N., Hackney, A. C., Heikura, I. A., Melin, A., Pensgaard, A. M., Stellingwerff, T., Sundgot-Borgen, J. K., Torstveit, M. K., Jacobsen, A. U., Verhagen, E., Budgett, R., Engebretsen, L., & Erdener, U. (2023). 2023 International Olympic Committee's (IOC) consensus statement on Relative Energy Deficiency in Sport (REDs). *British Journal of Sports Medicine*, 57(17), 1073–1097. <https://doi.org/10.1136/bjsports-2023-106994>
- Nakanishi, Y., Suzuki, Y., Sakurai, S., Fujita, S., Takaya, M., Sakuraba, K. (2019). Estimation of visceral fat area using an eight-polar bioelectrical impedance analyzer. *Journal of Clinical Physiology*, 49, 175–181. https://doi.org/10.34363/jocp.49.5_175
- Papageorgiou, M., Dolan, E., Elliott-Sale, K. J., & Sale, C. (2018). Reduced energy availability: implications for bone health in physically active populations. *European Journal of Nutrition*, 57(3), 847–859. <https://doi.org/10.1007/s00394-017-1498-8>
- Pritchett, K., DiFolco, A., Glasgow, S., Pritchett, R., Williams, K., Stellingwerff, T., Roney, P., Scaroni, S., & Broad, E. (2021). Risk of low energy availability in National and International level paralympic athletes: An exploratory investigation. *Nutrients*, 13(3), 979. <https://doi.org/10.3390/nu13030979>
- Rogers, M. A., Appaneal, R. N., Hughes, D., Vlahovich, N., Waddington, G., Burke, L. M., & Drew, M. (2021). Prevalence of impaired physiological function consistent with Relative Energy Deficiency in Sport (RED-S): An Australian elite and pre-elite cohort. *British Journal of Sports Medicine*, 55(1), 38–45. <https://doi.org/10.1136/bjsports-2019-101517>
- Siedler, M. R., De Souza, M. J., Albracht-Schulte, K., Sekiguchi, Y., & Tinsley, G. M. (2023). The influence of energy balance and availability on resting metabolic rate: Implications for assessment and future research directions. *Sports Medicine (Auckland, N.Z.)*, 53(8), 1507–1526. <https://doi.org/10.1007/s40279-023-01856-7>
- Silva, A. M., Santos, D. A., Matias, C. N., Minderico, C. S., Schoeller, D. A., & Sardinha, L. B. (2013). Total energy expenditure assessment in elite junior basketball players: a validation study using doubly labeled water. *Journal of Strength and Conditioning Research*, 27(7), 1920–1927. <https://doi.org/10.1519/JSC.0b013e31827361eb>
- Sim, A. & Burns, S.F. (2021). Review: Questionnaires as measures for low energy availability (LEA) and relative energy deficiency in sport (RED-S) in athletes. *Journal of Eating Disorders*, 9(1): 41. <https://doi.org/10.1186/s40337-021-00396-7>
- Slater, J., McLay-Cooke, R., Brown, R. & Black, K. (2016). Female recreational exercisers at risk for low energy availability. *International Journal of Sport Nutrition and Exercise Metabolism*, 26(5): 421-427. <https://doi.org/10.1123/ijsnem.2015-0245>
- Staal, S., Sjødin, A., Fahrenholtz, I., Bonnesen, K. & Melin, A.K. (2018). Low RMR ratio as a surrogate- marker for energy deficiency, the choice of predictive equation vital for correctly identifying male and female ballet dancers at risk. *International Journal of Sport Nutrition and Exercise Metabolism*, 28(4), 412-418. <https://doi.org/10.1123/ijsnem.2017-0327>
- Sterninger, T. & Larson-Meyer, D.E. (2022). RMR ratio as a surrogate marker for low energy availability. *Current Nutrition Reports*, 11(2), 263-272. <https://doi.org/10.1007/s13668-021-00385-x>
- Taguchi, M., Takata, K., Torii, S., Tanaka, T. (2018) Consideration of energy availability application in Japanese female athletes [in Japanese]. *The journal of Japanese Society of Clinical Sports Medicine*, 26, 5-11.
- Thomas, D.T., Erdman, K.A. & Burke, L.M. (2016). American College of Sports Medicine joint position statement. Nutrition and athletic performance. *Medicine and Science in Sports and Exercise*, 48(3), 543-568. <https://doi.org/10.1249/MSS.0000000000000852>

- Watanabe, Y., Kumahara, H., Nishimura, T., Katafuchi, N., Hirakata, M., Koshimizu, T., Yamato, T. (2024). Menstrual cycle status, energy availability, and dietary intake of female high school distance runners: An aspect of national competition-level athlete assessed using an accelerometer [in Japanese]. *Japanese Journal of Sports Nutrition*, 17, 95-105. https://doi.org/10.69214/jjsn.17.1_95
- Weir, J.B.D.B. (1949). New methods for calculating metabolic rate with special reference to protein metabolism. *Journal of Physiology*, 109(1-2), 1-9. <https://doi.org/10.1113/jphysiol.1949.sp004363>
- Witkoś, J., Błażejowski, G. & Gierach, M. (2023). The Low Energy Availability in Females Questionnaire (LEAF-Q) as a useful tool to identify female triathletes at risk for menstrual disorders related to low energy availability. *Nutrients*, 15(3), 650. <https://doi.org/10.3390/nu15030650>
- Yoshida, A., Ishikawa-Takata, K., Bessho, K., Taguchi, M., Tatsuta, W., Totani, M. & Higuchi, M. (2012). Factors associated with reporting error for energy intake estimated by food records in female athletes. *Japanese Journal of Nutrition and Dietetics*, 70(5), 305-315. <https://doi.org/10.5264/eiyogakuzashi.70.305>
- Yoshida, A., Ishikawa-Takata, K., Suzuki, N., Kushibe, S., Iso, S., Taguchi, M., Tanaka, S. & Higuchi, M. (2015). A new approach to assessment of energy expenditure during physical training *Japanese Journal of Physical Fitness and Sports Medicine*, 64(1), 125-134. <https://doi.org/10.7600/jspfs.64.125>