Time-of-Day of Energy Intake Is Associated with Body Fat Percentage in Japanese Female University Rhythmic Gymnasts and Non-Athlete Students

Saya MATSUSHITA1, Misuzu HASHIZUME2, Kumiko KISARA3, Yuri YOKOYAMA1, Ayaka KOTEMORI1, Yuki TADA1, Azumi HIDA1, Yukio YOSHIMURA4, Sakuko ISHIZAKI1 and Yukari KAWANO1

1Department of Food and Nutritional Science, Faculty of Applied Bio-Science, Tokyo University of Agriculture, 1–1–1 Sakuragaoka, Setagaya-ku, Tokyo 156–8502, Japan
2Inamishi High School, 4851 Nishiharuchika, Ina, Nagano 399–4431, Japan
3Department of Sport Wellness Science, Faculty of Sport and Health Sciences, Japan Women’s College of Physical Education, 8–19–1 Kitakarasuyama, Setagaya-ku, Tokyo 157–8565, Japan
4Faculty of Human Life Science, Shikoku University, 123–1 Furukawa-ebisuno, Ojincho, Tokushima 771–1192, Japan

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Summary This study investigated whether body fat percentage (BF%) in Japanese female university rhythmic gymnasts (RG) and non-athletes (control) was associated with the time-of-day of energy intake. A total of 57 females (RG group, n=34; control group, n=23) completed 24-h dietary recall surveys on 3 non-consecutive days. BF% was measured using a bioelectrical impedance analyzer after overnight fasting. Energy intake was stratified by time-of-day: morning (3:00 to 11:00), midday (11:00 to 17:00), evening (17:00 to 21:00), and nighttime (21:00 to 3:00). There was no significant difference between the groups in total energy intake, body weight, or body mass index. The RG group had significantly higher energy expenditure, a larger negative energy balance and lower BF% than the control group. The energy intake ratios (ER%) in the evening and at nighttime in the RG group were significantly lower and higher than in the control group, respectively. Total energy intake and energy balance did not show any significant association with BF% in either group. Multivariate linear regression with substitution model indicated that a substitution of ER% in the morning for ER% at nighttime was negatively associated with BF% after adjusting for confounding factors (β=-0.240; 95% confidence interval (CI): -0.455, -0.025) in the control group. In the RG group, a substitution of ER% in the evening for ER% at nighttime was negatively associated with BF% (β=-0.117; 95%CI: -0.214, -0.019). These results suggest that the timing of energy intake throughout the day is associated with BF% in Japanese university RG and non-athlete female students.

Key Words 24-h dietary recall survey, timing of energy intake, energy intake ratio (ER%), body composition, substitution model

In Japan, the average body mass index (BMI) of young adult females in their 20s has steadily declined since 1976, and the incidence of underweight (BMI<18.5 kg/m2) females in their 20s was reported to be 20.7% in 2016 (https://www.mhlw.go.jp/stf/houdou/0000177189.html). The daily energy intake in Japanese females in their 20s was reported to be only 1,631 kcal in 2016 (https://www.mhlw.go.jp/stf/houdou/0000177189.html). Despite these reports, both young and middle-aged females in Japan have a significantly high desire for thinness, even those who are not overweight. Mase et al. conducted a questionnaire survey of 631 Japanese female students and reported that 88.8% of normal-weight students had a desire for thinness (1). However, based on data from the third USA National Health and Nutrition Examination Survey, Romero-Corral et al. (2) reported that normal body weight (BW) obesity (hidden obesity), defined as the combination of normal body mass index (BMI) and high body fat percentage (BF%), was independently associated with increased risk for cardiovascular mortality in females. Nishida and Sakakibara (3) also reported in 2010 that underweight females in their 20 s and 30 s in Japan can be at risk for low lymphocyte count or potential malnutrition. The Developmental Origins of Health and Diseases concept proposes that infants with low birth weight (LBW) born from young malnourished females have a high risk of lifestyle-related diseases in the future (4). In Japan, the incidence of LBW infants has increased steadily from 5.1% in 1975 to 9.6% in 2009. Therefore, dietary efforts to improve underweight, hidden obesity or malnutrition and to achieve a healthy BW or body composition, including BF%,...
among females in their 20s are urgent in Japan (http://www.nibiohn.go.jp/eiken/kenkounippon21/en/kenkounippon21/) and the United States (2).

On the other hand, rhythmic gymnastics is a competitive, aesthetic sport in which appearance is an important scoring element. Therefore, keeping an ideal body shape and body composition with a low BF% is also a serious concern for athletes aiming for performance improvement. However, rhythmic gymnastics students also have misconceptions of their self-body image, and sometimes lose weight or maintain leanness through restrictive eating, reducing meals, or skipping meals (5). A previous study on rhythmic gymnasts (RG) at the elite national level reported that although daily energy expenditure in the RG group was much higher than the control group, energy intake was similar in both the RG and control groups, and that calcium, iron, and zinc intake were less than 100% of the recommended dietary allowance (RDA) in both groups (6). All RG were dieting in spite of the fact that they were extremely lean, and delayed maturity, menstrual irregularities, energy deficit, high training volume, and high frequency of injuries were common in the RG group (7). Lower energy intake is sometimes related to low intakes of many nutrients, and often results in malnutrition, anemia, iron deficiency or chronic within-day energy deficits (5–8). Physicians, parents, and coaches have pointed out the need for guidance to correct errors in dietary behaviors, to avoid excessive food restrictions (6), and to learn more about risk factors (7). Therefore, appropriate dietary supports and methods to achieve an ideal BW and body composition, including BF%, for optimum health and athletic performance are required.

Recently, numerous studies have reported that meal timing over the daily 24-h cycle may play an important role in improving and maintaining healthy body composition, BMI, BW, and BF% (9–13). McHill et al. (9) conducted a 30-d cross-sectional study targeting non-lean (high body fat) participants and reported that consumption of food during the circadian evening and/or night plays an important role in body composition. Bo et al. (10) also conducted a population-based cohort study of non-obese, non-diabetic middle-aged adults, and reported an increased risk of obesity and metabolic syndrome in participants who had a higher energy intake ratio (ER%) at dinner. However, no studies have examined the relationship between the timing of energy intake and healthy BW or body composition that includes ideal BF% in young Japanese females in their 20s. In addition, Sasaki et al. (11–13) examined the relationship between two exercise sessions per day and healthy BW in high fat diet-induced mice, and reported that eating meals before running attenuated high fat diet-induced obesity. They suggested the possibility that the timing of exercise also might play an important role in maintaining healthy BW or body composition, including BF%, in addition to the dietary timing of energy intake.

Thus, in this cross-sectional study, we investigated the actual state of the daily distribution of energy intake between female RG with a high training volume (RG group) and sedentary non-athlete females (control group) using a 24-h dietary recall method (24hDR), and compared the difference in energy intake distribution. In the RG group, training episodes were also investigated. The aim of this study was to explore the timing of energy intake in order to achieve a healthy body composition, including BF%, in Japanese university RG and non-athlete females.

**METHODS**

**Participants.** The RG group consisted of 34 female student athletes belonging to the rhythmic gymnastics team of Japan Women’s College of Physical Education, and the control group consisted of 23 female students without exercise habits at Tokyo University of Agriculture. The objective and methods of this study were verbally explained, and consent was obtained from each participant or the participant’s guardian prior to study enrollment. The study was conducted after obtaining approval from the ethics committee of the Tokyo University of Agriculture (Approval No. 1602).

**Anthropometric measurements and 24hDR.** Measurements were carried out under overnight fasting conditions of 10 h or more in September 2015. Height was measured using a stadiometer (ST-2M: Yagami Inc., Nagoya, Japan) with bare feet and light clothing (e.g., t-shirt and training shorts). BW and BF% were measured to one decimal point using a bioelectrical impedance analyzer (InBody 430; InBody Japan, Inc., Tokyo, Japan). BMI was calculated as the BW divided by height squared (kg/m²).

Participants attended a 24hDR interview for 3 d at about weekly intervals (2 weekdays and 1 weekend day) in which they were asked to list all foods and drinks they consumed, and their daily activities for 24 h from 3:00 on the day before the interview until 3:00 on the day of the interview. The interviews were randomly conducted by well-trained interviewers according to the previously described multiple-pass interviewing method (14, 15). Daily energy intakes based on the Standard Tables of Food Composition in Japan (5th revised and enlarged edition) (16) were calculated using nutrient calculation software (Excel Eiyoukun, Version 7.0; Kenpaku-sha, Tokyo, Japan). Meals were split by time-of-day into morning (meals consumed from 3:00 to 11:00), midday (11:00 to 17:00), evening (17:00 to 21:00), and nighttime (21:00 to 3:00), partially modified according to a previous report (17). Then, ER% was calculated as each individual’s energy intake during each meal time divided by the total energy intake over 24 h.

Daily energy expenditure (EE) was calculated by multiplying each individual’s basal metabolic rate (BMR) with the individual activity level as assessed by metabolic equivalents (http://www0.nih.go.jp/eiken/programs/2011mets.pdf). BMR was estimated using the Harris-Benedict equation. Energy balance was calculated as the difference between total energy intake and total EE (18), as follows: energy balance (kcal/d)=total energy intake (kcal/d)−total EE (kcal/d).
Meal Timing and Body Fat Percentage

Table 1. Participant characteristics.

<table>
<thead>
<tr>
<th></th>
<th>Control group (n = 23)</th>
<th>RG group (n = 34)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age¹ (y)</td>
<td>21.5±2.0</td>
<td>18.9±0.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Age of menarche¹ (y)</td>
<td>12.9±2.4</td>
<td>14.7±1.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Height¹ (cm)</td>
<td>158.6±4.5</td>
<td>158.5±5.1</td>
<td>0.845</td>
</tr>
<tr>
<td>BW¹ (kg)</td>
<td>50.1±5.5</td>
<td>51.0±3.8</td>
<td>0.139</td>
</tr>
<tr>
<td>BMI¹ (kg/m²)</td>
<td>19.9±1.8</td>
<td>20.3±1.5</td>
<td>0.172</td>
</tr>
<tr>
<td>Body fat mass¹ (kg)</td>
<td>12.0±3.2</td>
<td>10.6±2.3</td>
<td>0.085</td>
</tr>
<tr>
<td>BF%² (%)</td>
<td>23.8±5.2</td>
<td>20.7±3.4</td>
<td>0.016</td>
</tr>
<tr>
<td>Lean body mass² (kg)</td>
<td>38.1±4.2</td>
<td>40.4±2.5</td>
<td>0.025</td>
</tr>
<tr>
<td>Total EE² (kcal)</td>
<td>1907±204</td>
<td>2317±261</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>EE per BW² (kcal/kg BW)</td>
<td>38.1±2.7</td>
<td>45.5±3.8</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

**Energy balance³**

<table>
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<tr>
<th></th>
<th>Control group</th>
<th>RG group</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily total³ (kcal)</td>
<td>1,730±294</td>
<td>1,670±472</td>
<td>0.587</td>
</tr>
<tr>
<td>Morning³ (kcal)</td>
<td>409±183</td>
<td>417±198</td>
<td>0.867</td>
</tr>
<tr>
<td>Midday³ (kcal)</td>
<td>591±141</td>
<td>539±229</td>
<td>0.331</td>
</tr>
<tr>
<td>Evening³ (kcal)</td>
<td>493±210</td>
<td>310±284</td>
<td>0.004</td>
</tr>
<tr>
<td>Nighttime³ (kcal)</td>
<td>237±238</td>
<td>404±243</td>
<td>0.009</td>
</tr>
</tbody>
</table>

**Meal ER%**

<table>
<thead>
<tr>
<th></th>
<th>Control group</th>
<th>RG group</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning ER%² (%)</td>
<td>23.9±11.7</td>
<td>25.5±11.3</td>
<td>0.595</td>
</tr>
<tr>
<td>Midday ER%² (%)</td>
<td>35.2±10.0</td>
<td>31.9±8.6</td>
<td>0.184</td>
</tr>
<tr>
<td>Evening ER%³ (%)</td>
<td>27.8±12.1</td>
<td>18.3±15.1</td>
<td>0.014</td>
</tr>
<tr>
<td>Nighttime ER%³ (%)</td>
<td>13.1±12.6</td>
<td>24.3±13.3</td>
<td>0.002</td>
</tr>
</tbody>
</table>

RG: rhythmic gymnasts; BMI: body mass index; BF%: body fat percentage; EE: energy expenditure; ER%: meal energy intake ratio. Energy balance was calculated as the difference between total energy intake and total EE in accordance with Guebels et al. (18). We divided meal times into four categories: morning (3:00 to 11:00), midday (11:00 to 17:00), evening (17:00 to 21:00) and nighttime (21:00 to 3:00) based on 24-h dietary records for 3 non-consecutive days. ER% was defined as each individual’s energy intake during each meal time divided by the total energy intake over 24 h.¹ Mann-Whitney U test, ² Non-paired t-test.

**RESULTS**

**Participant characteristics**

The characteristics of the participants are shown in

**Hourly incidence of eating or participation in rhythmic gymnastics training.** Previous meal timing studies in humans have either allowed the participants to define their own meal timing (i.e., when they eat breakfast and dinner) (9, 10), or used pre-defined meal times based on a 24-h/d cycle (11–13, 17). Although the latter is more beneficial from the perspective of time-of-day analysis, not many studies have defined meal timing based on a 24-h/d cycle. A 24hDR method allows the interviewer to question the participants directly about the time that all food and beverages were consumed, which could be considered an ideal method for investigating meal timing.

Consuming food with a caloric content of 50 kcal or more within one time period (19) was defined as one episode of meal eating, and an individual’s incidence of hourly meal episodes and energy intake for 3 d in total were calculated for each 24-h period. In addition, we asked all participants for the start and end time of their training session and calculated the percentage of each individual’s hourly incidence of RG training activity against that of all participants for each 24-h period.

**Statistical analysis.** Data are basically presented as mean±standard deviation. For the analysis of energy and macronutrient intake or the hourly episode incidence ratio of meal timing and rhythmic gymnastics training, the average of the data obtained from 3 d of the 24hDR was used as the individual’s representative value. A Shapiro-Wilk test was performed in advance to test the normality of all the data. Subsequently, an unpaired t-test or Mann-Whitney U test was conducted. Pearson’s correlation analysis was used to determine the correlation between BF% and each of BW, lean body mass, daily EE, energy balance, circadian timing of ER% (i.e., ER% in the morning, at midday, in the evening, and at nighttime), and total energy intake. A multiple linear regression analysis was used to determine the relationship between BF% as a dependent variable and ER% (in the morning, at midday, in the evening, and at nighttime) as independent variables using substitution models (20, 21) adjusted for total energy intake and EE. Statistical analysis was performed with IBM SPSS Statistics ver. 23 (IBM Corp., Armonk, NY, USA). The significance level was set at p<0.05.
Table 1. Age and BF% were significantly lower in the RG group compared to the control group (age, \( p < 0.001 \); BF\%, \( p = 0.016 \)). The RG group had significantly higher menarche age (\( p < 0.001 \)), lean body mass (\( p = 0.025 \)), and EE (\( p < 0.001 \)), and a larger negative energy balance (\( p = 0.001 \)) than the control group. However, there was no significant difference in the height, BW, and BMI between the groups. No significant differences were observed between the groups in daily total energy intake, or in energy intake in the morning and at midday. However, in the evening, the energy intake and ER\% of the RG group were significantly lower than those of the control group. At nighttime, the energy intake and ER\% of the RG group were significantly higher than those of the control group.

**Daily distribution of energy intake**

Figure 1 shows the overall hourly mean energy intake for 3 d over the course of 24 h. In the control group, three peaks in energy intake were observed, one between 6:00 and 8:00, one at 12:00, and one...
between 18:00 and 20:00. The highest energy intake was 360 kcal/h at 12:00. On the other hand, energy intake in the RG group occurred relatively later than in the control group. Three peaks were also observed in the RG group, but they occurred between 7:00 and 9:00, between 12:00 and 14:00, and between 19:00 and 22:00. The highest energy intake was 167 kcal/h at 22:00, but a similar energy intake of 161 kcal/h was observed at 13:00.

Incidence of energy intake and training over 24 h in the RG group

Figure 2 shows the overall hourly mean episode incidence ratios for energy intake and participating in rhythmic gymnastics training over the course of 24 h for 3 d in the RG group. Rhythmic gymnastics training was performed over approximately 14 h from 7:00 to 21:00. Forty percent or more of the participants attended their daily training at 8:00, at 12:00, and between 17:00 and 20:00.

Relationship between BF% and energy ratio for each meal time

There was no significant relationship between BF% and EE, total energy intake, and energy balance in the control group. In the RG group, there was no significant relationship between BF% and total energy intake and energy balance, but a positive correlation was observed with EE ($r = 0.343$, $p = 0.047$).

When the relationship between BF% and ER% at each meal time was examined (Fig. 3), BF% had a significant negative relationship only with the ER% in the morning (3:00 to 11:00), midday (11:00 to 17:00), evening (17:00 to 21:00), and nighttime (21:00 to 3:00) based on the 24-h dietary record. The diagram shows the distribution of energy intake ratios (ER%) at each meal time against BF%.

Control group: (a) to (d); RG group: (e) to (h). ER% was defined as the energy intake percentage during each meal time divided by the total energy intake over 24 h. BF%: body fat percentage; RG: rhythmic gymnasts. $r$ values are Pearson’s correlation coefficients.
In this study, we investigated the association between BF% and ER% in the morning, at midday, and at nighttime among Japanese female university RG and a non-athletic control group. Our results showed that the timing of energy intake throughout the day plays an important role in achieving healthy body composition, including BF%, in Japanese university RG and sedentary non-athlete female students, and that morning in the control group and evening in the RG group might be the most reasonable times of energy intake.

In general, any increase or decrease in BF% is determined by the balance between energy intake and daily EE. As for energy balance, Guebels et al. (18) investigated the effect of energy supplementation (360 kcal/d) for 6 mo in females with exercise-related menstrual dysfunction, and reported that although the energy supple-

| Table 2. Association between BF% and ER% with a 1% ER% substitution in daily meal intake. |
|---------------------------------------------|---------------------------------------------|
| Model 1 | Model 2 |
| **Control group (n=23)** | **Model 1** | **Model 2** |
| Evening ER% substituted for | | |
| Morning ER% | \(-0.307\) <i>(-0.548--0.066)</i> | \(-0.233\) <i>(-0.470--0.005)</i> |
| Midday ER% | \(-0.178\) <i>(-0.447--0.092)</i> | \(-0.169\) <i>(-0.419--0.082)</i> |
| Nighttime ER% | \(-0.052\) <i>(-0.260--0.156)</i> | \(0.007\) <i>(-0.196--0.211)</i> |
| Nighttime ER% substituted for | | |
| Morning ER% | \(-0.255\) <i>(-0.488--0.024)</i> | \(-0.240\) <i>(-0.455--0.025)</i> |
| Midday ER% | \(-0.125\) <i>(-0.444--0.193)</i> | \(-0.176\) <i>(-0.477--0.124)</i> |
| Evening ER% | \(0.052\) <i>(-0.158--0.260)</i> | \(-0.007\) <i>(-0.211--0.196)</i> |

| \(95\% CI\): 95% confidence interval; ER%: meal energy intake ratio; RG: rhythmic gymnasts. We divided meal times into four categories: morning (3:00 to 11:00), midday (11:00 to 17:00), evening (17:00 to 21:00), and nighttime (21:00 to 3:00) based on 24-h dietary records for 3 non-consecutive days. ER% was defined as the energy intake percentage during each meal time divided by the total energy intake over 24 h. A multiple regression analysis was used to examine the relationship between BF% as a dependent variable and the ER% in each of morning, midday, evening, and nighttime as independent variables using a substitution model. Model 1 was adjusted for total energy (kcal/d). Model 2 was further adjusted for daily energy expenditure (kcal/kg BW/d). Numbers in bold are statistically significant (\(p<0.05\)). |

morning (\(r=-0.452, p=0.030\) in the control group; however, there was no significant relationship with the ER% at other meal times (Fig. 3a–d). In the RG group, there was no significant relationship between BF% and the ER% in the morning or at midday, but there was a significant negative relationship with the ER% in the evening (\(r=-0.371, p=0.031\)) and a significant positive relationship with the ER% at nighttime (\(r=0.353, p=0.041\)) (Fig. 3e–h).

Table 2 presents the \(\beta\) estimates from multiple linear regression analyses using a substitution model; this indicates the association between BF% and ER% when an ER of 1% in the evening or at nighttime is substituted for an ER of 1% at other meal times. In the control group, when the ER% in the evening or at nighttime was substituted for the ER% at other meal times, a negative linear relationship was observed between BF% and the ER% in the evening in Model 1 (evening, \(\beta=-0.307, 95\% CI:\ -0.548--0.066\); nighttime, \(\beta=-0.255, 95\% CI:\ -0.488--0.024\)). Furthermore, after adjusting for EE (kcal/kg BW) in Model 2, a significant negative association was only observed when the ER% at nighttime was substituted for the ER% in the evening (\(\beta=-0.240, 95\% CI:\ -0.455--0.025\)). On the other hand, in the RG group, when the ER% in the evening was substituted for the ER% at the other meal times, the association was reversed. After adjusting for EE (kcal/kg BW) in Model 2, when the ER% in the evening was substituted for the ER% at nighttime, a higher ER% at nighttime was associated with higher BF% (\(\beta=0.117, 95\% CI:\ 0.019, 0.214\)). On the other hand, when the ER% at nighttime was substituted for the ER% at the other meal times, there was a significant negative association between BF% and the ER% in the evening (\(\beta=-0.117, 95\% CI:\ -0.214, -0.019\)).

DISCUSSION

In this study, we investigated the association between BF% and the ER% in the morning, at midday, and at nighttime among Japanese female university RG and a non-athletic control group. Our results showed that the timing of energy intake throughout the day plays an important role in achieving healthy body composition, including BF%, in Japanese university RG and sedentary non-athlete female students, and that morning in the control group and evening in the RG group might be the most reasonable times of energy intake.

In general, any increase or decrease in BF% is determined by the balance between energy intake and daily EE. As for energy balance, Guebels et al. (18) investigated the effect of energy supplementation (360 kcal/d) for 6 mo in females with exercise-related menstrual dysfunction, and reported that although the energy supple-
Meal Timing and Body Fat Percentage

In this study, we observed that a substitution of ER% in the morning in the control group or in the evening in the RG group for the ER% at nighttime was negatively associated with BF%. McHill et al. (9) examined the relationship between the timing of food consumption relative to clock hour and endogenous circadian time, content of food intake, and body composition among 110 participants aged 18–22 y. They reported that non-lean participants (high BF) consumed most of their energy 1.1 h closer to melatonin onset than did lean individuals (low BF), and that individuals who consumed a greater percentage of their daily energy between 4 h before dim-light melatonin onset (DLMO), which established marker of circadian phase and onset of biological night, had a higher BF%. Furthermore, they reported that the timing of the energy midpoint relative to DLMO was the only variable significantly associated with the BF%. Wang et al. (17) examined the association between BMI and energy intake in the morning (00:00–11:00), at midday (11:00–17:00), and in the evening (17:00–00:00), and reported that eating more of the day’s total energy intake in the evening was associated with a higher risk of high BMI. Furthermore, Bo et al. (10) designed a population based-cohort study in 1,245 non-obese, non-diabetic participants aged 45–64 y, dividing them into three groups according to tertile of percent daily energy intake at dinner (meal consumed from 19:00 to 22:00); they reported that the highest tertile showed an increased risk of obesity, metabolic syndrome, and non-alcoholic fatty liver disease.

In our present study, we divided meal time-of-day into morning (3:00 to 11:00), midday (11:00 to 17:00), evening (17:00 to 21:00), and nighttime (21:00 to 3:00). Therefore, our present observation might support these previous observations; when the ER% at nighttime was substituted for the ER% at other meals times, there was a negative association between BF% and the ER% in the other meal times in both groups. Lombardo et al. (22) examined the effects of two low-energy diets with different distributions throughout the day on weight loss and other major obesity-related metabolic parameters in 36 non-smoking homemakers, and reported that 3 mo after the intervention, a low-energy Mediterranean diet (600 kcal daily deficit compared to the total EE) showed significant improvements in body composition and metabolic parameters, and that a diet in which 70% of the daily energy intake are consumed in the first part of the day (breakfast, morning snack and lunch) could enhance the results of these improvements compared from a diet in which 55% of the daily energy intake are consumed in the first part of the day. Although a potential mechanism for increased BF% in response to later meal timing may be concerned with decreased diet-induced thermogenesis (DIT) (23). McHill et al. (9) suggested another possibility that eating closer to or after DLMO may have a lower DIT response, which would contribute to a positive energy balance and weight gain over time.

In connection with the role of breakfast, we previously investigated whether delayed or advanced meal timing in the first part of the day affected circadian rhythm as assessed by heart rate variability (HRV) (24, 25), and reported that the amplitude of low frequency power, high frequency (HF) power and the ratio of HF power to total power over a 24-h period were not significantly different. However, acrophase was significantly affected by meal timing, and serum triglyceride and total and high-density lipoprotein cholesterol also increased or decreased with delayed or advanced meal timing, respectively. Thus, we suggest the possibility that the timing of breakfast might be a key factor in regulating circadian phase alignment of the autonomic nervous system or lipid metabolism (25). Therefore, all the above observations correspond well with our finding in the control group that ER% in the morning might play the most important role in achieving healthy body composition with increased DIT or regulating circadian phase alignment.

On the other hand, in the RG group, 35.3% of the participants consumed the highest (308 kcal) energy throughout the day over only 2 h at nighttime (21:00 to 23:00). In addition, in the RG group, 40% or more of the participants were training at 8:00 (morning), 12:00 (midday) and 17:00 to 20:00 (evening). Erdman et al. (26) reported similar observations in elite Canadian athletes in which both male and female athletes consumed their greatest source of food energy during the evening meal and afternoon snack, with breakfast having the lowest meal energy intake. Sasaki et al. (11–13) previously reported that a high-fat diet before exercising in mice was more effective in controlling weight gain than a high-fat diet after exercising. When obese mice fed a high-fat diet for several weeks were exposed to a combination of feeding and exercise timing in an effort to reduce BW, eating followed by exercise resulted in greater weight loss and reduced respiratory quotient (11, 12). Then, they reported a possibility that lipid consumption for EE explain the attenuated gains of both BW and BF. In addition, forced treadmill exercise, rather than voluntary wheel running exercise, produced phase advance in peripheral clocks depending on the time of exercise (13). Moreover, exercise-induced phase shifts of peripheral clocks were accompanied by increased levels of corticosterone and norepinephrine in peripheral tissues, and adrenalectomy with norepinephrine receptor blockers completely blocked the treadmill exercise-induced entrainment (13). It is well accepted that serum concentrations of cortisol, epinephrine or norepinephrine increase significantly just after physical exercise. Since increased concentrations of cortisol, epinephrine or norepinephrine cooperate to enhance lipolysis in adipose tissue, this might result in BF% loss.
feeding at nighttime after the exercise might be associated with obesity due to phase-delay of the peripheral clock (9, 27, 28). Therefore, in the RG group, a substitution of ER% in the evening for ER% at nighttime means both higher ER% in the evening before the training and lower ER% at nighttime after the training, suggesting a possibility that a substitution of ER% in the evening before the training result in a loss of BF% due to both activations of the adrenal gland and the sympathetic nervous system and a phase advance of the peripheral clock (13).

The limitations of this study were as follows: i) the small number of participants may have contributed to the lack of detection power, and the participants consisted of only two types of female university students: RG and non-athletes; ii) due to the cross-sectional design, a causal relationship between BF% and meal times could not be established. To clarify the relationship between the timing of meal intake or exercise and ideal healthy BW or body composition, including BF%, further estimation of serum concentrations of melatonin, cortisol, epinephrine or norepinephrine should be included in randomized intervention studies in humans; iii) BF% measurements were carried out using a bioelectrical impedance analyzer. Therefore, BF% in this study may not necessarily be a true value. Shitara et al. (29) examined the differences in BF% measurements in 73 healthy Japanese male adults using various methods, and reported that the difference between bioelectrical impedance analyzer and dual-energy X-ray absorptiometry measurements was 1.7±2.0%, and that the bioelectrical impedance analyzer (InBody 730) is a highly accurate method for BF% evaluation; iv) daily EE was not an actual measured value; v) the average data obtained from only 3 d of the 24hDR was used as the individual’s representative value. Therefore, there is a possibility that the participants’ habitual life was not necessarily reflected; vi) we investigated the relationship between BF% and only the timing of energy intake through the day, but the detailed relationship between BF% and various nutrients (e.g., carbohydrate, protein, fat, etc.) besides energy is unknown; vii) at this time, we did not investigate the relationship between body composition and sleeping time; however, some studies suggest there is a relationship (27, 28). Our participants in both groups were university students, and episodes of energy intake were observed in both groups from 3:00 to 1:00. Therefore, there might be no difference between the groups at bedtime. However, further studies are needed to clarify the relationship between BF% and sleeping time; and viii) since this study was undertaken during the regular rhythmic gymnastics training season, we did not take how RG eat during the competition period into consideration. Therefore, caution should be exercised when interpreting these research findings.

Despite these limitations, the significance of this study lies in the possibility that the daily training time may have affected the meal timing in the RG group, and that meal timing, especially at nighttime, may have an association with lower BF% in both Japanese female university RG and sedentary non-athlete students.

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Author contributions
This study was designed by MH, KK, Y Yoshimura, SL, and YK; data were collected and analyzed by SM, Y Yokoyama, AK, KK, and SI; data interpretation and manuscript preparation were undertaken by MH, YT, AH, and YK; SM, Y Yoshimura, and YK drafted the manuscript; and Y Yokoyama and AK critically reviewed the manuscript; and YK revised the manuscript. All authors approved the final version of the paper.

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