Effect of Breakfast Omission on Energy Intake and Evening Exercise Performance

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ABSTRACT

CLAYTON, D. J., A. BARUTCU, C. MACHIN, D. J. STENSEL, and L. J. JAMES. Effect of Breakfast Omission on Energy Intake and Evening Exercise Performance. Med. Sci. Sports Exerc., Vol. 47, No. 12, pp. 2645–2652, 2015. Introduction: Breakfast omission may reduce daily energy intake. Exercising fasted impairs performance compared with exercising after breakfast, but the effect of breakfast omission on evening exercise performance is unknown. This study assessed the effect of omitting breakfast on evening exercise performance and within-day energy intake. Methods: Ten male, habitual breakfast eaters completed two trials in a randomized, counterbalanced order. Subjects arrived at the laboratory in an overnight-fasted state and either consumed or omitted a 733 ± 46 kcal (3095 ± 195 kJ) breakfast. Ad libitum energy intake was assessed at 4.5 h (lunch) and 11 h (dinner). At 9 h, subjects completed a 30-min cycling exercise at approximately 60% VO2peak, followed by a 30-min maximal cycling performance test. Food was not permitted for subjects once they left the laboratory after dinner until 0800 h the following morning. Acylated ghrelin, GLP-1(7–36), glucose, and insulin were assessed at 0, 4.5, and 9 h. Subjective appetite sensations were recorded throughout. Results: Energy intake was 199 ± 151 kcal greater at lunch (P < 0.01) after breakfast omission compared with that after breakfast consumption and tended to be greater at dinner after consuming breakfast (P = 0.052). Consequently, total ad libitum energy intake was similar between trials (P = 0.196), with 24-h energy intake 19% ± 5% greater after consuming breakfast (P < 0.001). Total work completed during the exercise performance test was 4.5% greater after breakfast (314 ± 53 vs 300 ± 56 kJ; P < 0.05). Insulin was greater during breakfast consumption at 4.5 h (P < 0.05), with no other interaction effect for hormone concentrations. Conclusions: Breakfast omission might be an effective means of reducing daily energy intake but may impair performance later that day, even after consuming lunch. Key Words: APPETITE, ENERGY RESTRICTION, ENERGY BALANCE, MEAL OMISSION, GHRELIN, GLP-1

maintenance of a stable body weight is achieved through careful management of energy balance, with weight gain occurring because of chronic surplus of energy intake above energy expenditure. Refraining from eating at a prescribed meal time will inevitably create an energy deficit, and breakfast omission (BO) is a frequently cited method of reducing energy intake (40). Regular breakfast consumption (BC) has been recommended as part of a “healthy balanced diet” (24), and individuals who regularly consume breakfast tend to have a lower body mass index (BMI) (3) and reduced prevalence of several chronic diseases including type 2 diabetes (26).

Traditionally, recommendations for regular BC have been based on correlation studies that associate lower BMI with regular BC (3). However, these findings do not infer causality, as individuals who regularly consume breakfast have often been shown to exhibit healthy lifestyle factors, such as increased physical activity (6) and improved dietary profiles (14). Therefore, it is difficult to elucidate whether improved weight control is mediated by BC per se.

Acute intervention studies have generally found that the omission of breakfast induces increased feelings of hunger over the morning, leading to greater energy intake in the first meal after BO (19,22). However, energy intake over the course of the day rarely results in complete compensation for the energy omitted at breakfast, consequently reducing daily energy intake (2,19,22,25,30). However, this is not a universal finding, as Astbury et al. (1) has found that energy omitted at breakfast was fully compensated for at an ad libitum lunch meal and Farshchi et al. (11) found energy intake to be greater after BO compared with that after BC. Although these studies investigated a similar topic, one of them used a liquid preload between breakfast and lunch to determine the hormonal response to BO (1) and the other balanced energy intake by providing cereal and milk at either 0700 or 1200 h, representing BC and omission, respectively (11).
Methods

Subjects. After ethical approval, subjects completed a medical screening questionnaire and provided a written informed consent. Subjects were 10 healthy, weight-stable (self-reported), recreationally active (<10 h·wk⁻¹) males (age, 22 ± 3 yr; weight, 73.1 ± 9.7 kg; height, 1.76 ± 0.05 m; BMI, 23.5 ± 3.2 kg·m⁻²; body fat, 17% ± 6%). Subjects regularly consumed breakfast and were not restrained, disinhibited, or hungry eaters, determined after completion of a three-factor eating questionnaire (35).

Preliminary trials. Subjects completed three preliminary trials. During the first trial, height (to nearest 0.1 cm) and weight (to nearest 0.02 kg) were measured and body fat percentage was estimated using skinfold calipers (10). A discontinuous incremental exercise test was also performed on an electrically braked cycle ergometer (Lode Corival, Groningen, Netherlands) to determine peak oxygen consumption (VO₂peak). Increments lasted for 4 min, were separated by approximately 5 min of rest, and increased until volitional exhaustion. Expired air was collected into a Douglas bag during the last minute of each increment. HR was measured (Polar Beat, Kempele, Finland), and subjects rated their perceived exertion (RPE) on a 6- to 20-point scale at the end of each increment. Expired air samples were analyzed for oxygen and carbon dioxide concentration (Servomex, Crowborough, United Kingdom), volume (Harvard Dry Gas Meter; Harvard Ltd., Edenbridge, United Kingdom), and temperature (Edale, Cambridge, United Kingdom).

During the second preliminary trial, subjects were fully familiarized with the experimental protocol (described in detail in the following section), with the exception that subjects were permitted to come and go from the laboratory between feeding periods and the exercise protocol. On the third preliminary trial, subjects completed the exercise protocol for a second time.

Pretrial standardization. In the 48 h preceding the first experimental trial, subjects completed a weighed food diary, replicating this in the 48 h preceding the second trial. Strenuous exercise and alcohol intake were not permitted during this period. Subjects traveled to and from the laboratory via motorized transport, arriving in the morning after an overnight fast of ≥10 h.

Protocol. Subjects completed two experimental trials: BC (BC) and BO. Trials were separated by at least 7 d, conducted at the same time of the day on the same day of the week, and were administered in a randomized, counterbalanced order. Subjects were aware that the aims of the study were to assess the effect of BO on appetite, energy intake, and exercise performance but were not aware of the hypothesis.

Subjects arrived at the laboratory at approximately 0730 h and were weighed, and a fasted blood sample was collected by venipuncture of an antecubital vein after 30 min of supine rest (0 h). Baseline measures of subjective appetite sensations on a visual analog scale were obtained before participants received either a standardized breakfast (BC) or no breakfast (BO). After breakfast (0.5 h), subjects rested quietly in the laboratory. A second blood sample was drawn at 1230 h (4.5 h), after which a multi-item ad libitum lunch buffet was served consisting of cold, ready-to-eat foods. Upon termination of the meal, subjects again rested in the laboratory. At 1700 h (9 h), a blood sample was drawn before subjects began the exercise protocol (described in the following section). One hour after completion of the performance test (11 h), an ad libitum pasta test meal was served. After the test meal (11.5 h), subjects were transported home and were instructed not to eat or drink anything other than plain water until they went to bed. Subjects returned to the laboratory after an overnight fast the following morning at 0800 h (24 h) for body mass measurement and to complete a subjective appetite sensations questionnaire. Ad libitum water and low-energy squash were available upon request throughout the study period and were provided with each buffet meal.
Ad libitum meals. Each ad libitum meal was provided in excess of expected consumption, and more food was available upon request. The lunch meal consisted of cooked meats, cheese, bread, butter, mayonnaise, salad, fruit, crisps, cereal bars, and biscuits (Tesco, Cheshunt, United Kingdom). The dinner meal consisted of pasta, cheese, tomato sauce, and olive oil (Tesco, Cheshunt, United Kingdom), was homogeneous in nature, providing 8.01 ± 0.04 kJ g⁻¹ (14%, 33%, and 53% of energy provided by protein, fat, and CHO, respectively), and was served as previously described (5). Meals were served in an isolated feeding laboratory with no interaction between subjects and investigators. Subjects were given 30 min to consume each meal and were explicitly instructed to eat until they felt “comfortably full and satisfied.” The amount consumed at each meal was quantified by weighing the food before and after consumption, with macronutrient content of foods ascertained from manufacturer values.

Exercise performance. Subjects began exercising at 1700 (9 h) and initially performed a 30-min steady-state and V˙ CO₂ values using stoichiometric equations (13). They were instructed to eat until they felt “comfortably full and satisfied.” The workload was set at 75% V˙ O₂peak, and sub- jects were given 30 min to consume each meal and were explicitly instructed to eat until the time remaining. During the steady-state exercise, expired air was collected between 14–15 and 29–30 min, and HR and RPE were obtained at the end of each collection. During the performance test, workload and HR were recorded every 5 min and RPE was recorded every 10 min. Energy expenditure and substrate utilization were calculated from V˙ O₂ and V˙ CO₂ values using stoichiometric equations (13).

Standardized breakfast meal. During BC, subjects were provided with a standardized breakfast meal of 25% estimated daily energy requirements, determined by multiplying resting metabolic rate (27) by a physical activity level of 1.7, to account for the exercise component of the trial. Breakfast consisted of creped rice cereal, semiskimmed milk, wholemeal bread, margarine, strawberry jam, and orange juice (Tesco, Cheshunt, United Kingdom) and amounted to 3095 ± 195 kJ, with 11%, 17%, and 72% of energy derived from protein, fat and CHO, respectively. During BO, subjects were provided with a bolus of water for breakfast equal to that contained within the BC trial. Subjects were instructed to consume the entire meal gradually over 30 min.

Subjective appetite sensations. Subjects rated their hunger, fullness, desire to eat (DTE), and prospective food consumption (PFC) on 100-mm visual analog scales at 0, 0.5, 2.5, 4.5, 5, 7, 9, 10, 11, 11.5, 13, and 24 h. Verbal anchors of “not at all/none at all” and “extremely/no desire at all/a lot” were placed at 0 and 100 mm, respectively.

Blood sampling and analysis. Blood samples (12 mL) were drawn after 30 min of supine rest, at 0 h (baseline), 4.5 h (prelunch), and 9 h (preexercise) via venipuncture of an antecubital vein. Five milliliters of blood was immediately mixed with 50-μL dipeptidyl peptidase 4 inhibitor (DPP4-010; Merck Millipore, Watford, United Kingdom) and dispensed into an EDTA tube (1.75 mg mL⁻¹) for determination of active glucagon-like peptide-1 (GLP1[7–36]) by ELISA (EGLP-35 K; Merck Millipore, Watford, United Kingdom). Two-and-a-half milliliters of blood was dispensed into an EDTA tube (1.75 mg mL⁻¹) for measurement of blood glucose concentration (GOD-PAP method; Randox Laboratories Ltd., Crumlin, United Kingdom) and insulin concentration by ELISA (DX-EIA-2935; Immunodiagnostic Systems, Boldon, United Kingdom).

All samples were centrifuged at 1750g for 15 min in a refrigerated centrifuge (4°C). After 10 min of centrifugation, the supernatant (1 mL) of the PHMB/PBS/NaOH-treated blood was combined with 1-M HCl (100 μL) before all samples were centrifuged for an additional 5 min. The supernatant of each sample was then removed and stored at −20°C until frozen and then transferred to −80°C for later analysis.

A separate 2 mL of blood was collected into an EDTA tube and used for the determination of hemoglobin (via the cyanmethemoglobin method) and hematocrit (via microcentrifugation) and used to estimate changes in plasma volume relative to baseline (9).

Statistical analysis. Data were analyzed using SPSS 21.0 (SPSS, Inc., Somers, NY). Area under the curve (AUC) values were calculated using the trapezoidal method and were averaged over time. Correction of plasma measures for changes in plasma volume did not alter the results, so the unadjusted values are presented. All data were checked for normality of distribution using the Shapiro–Wilk test. Data containing one factor were analyzed using a t-test or Wilcoxon signed-rank test, as appropriate. Data containing two variables were analyzed using a two-way ANOVA and, where appropriate, followed by Bonferroni-adjusted paired t-tests or Bonferroni-adjusted Wilcoxon signed-rank tests, as appropriate. Data sets were determined to be significantly different when P < 0.05. Data were found to be normally distributed, with the exception of all subjective appetite sensations, acylated ghrelin, and GLP-1[7–36], and were subject to nonparametric statistical analysis. However, data have been presented as means ± SD for consistency throughout, unless stated otherwise.

RESULTS

Energy and macronutrient intake. A breakfast of 3095 ± 195 kJ was provided during BC. Subsequent total ad libitum energy intake was 11,685 ± 1893 kJ compared...
with 11,329 ± 2117 kJ, for BO and BC, respectively (P = 0.196). At lunch, energy intake was greater during BO (5804 ± 1817 kJ) than that during BC (4970 ± 1987 kJ; P < 0.01), whereas at dinner, there was a tendency for greater energy intake during BC (6359 ± 1631 kJ) than that during BO (5882 ± 1443 kJ; P = 0.052). Including breakfast, total energy intake was 19% ± 5% greater during BC (14,424 ± 2255 kJ) than that during BO (11,685 ± 1893 kJ) (Fig. 1).

CHO (P < 0.05) and fat (P < 0.05) intake was greater at lunch during BO compared with that during BC, but there was no difference in protein (P = 0.142) or fiber (P = 0.314) intake. The dinner meal was homogeneous in nature; therefore, macronutrient selection could not be gauged from this meal. Including breakfast, total CHO, protein, and fiber intake were greater (P < 0.01) and fat intake tended to be greater (P = 0.068) during BC compared with those during BO (Table 1).

Subjective appetite sensations. All appetite sensations (hunger, fullness, DTE, and PFC) showed a main effect of trial (P < 0.05) and time (P < 0.001) as well as an interaction effect (P < 0.001) (Fig. 2). Subjects reported increased hunger, DTE, and PFC, as well as lower fullness, in the postbreakfast period (0.5–4.5 h) during BO compared with those during BC (P < 0.01). Subjects also reported increased fullness at 7 h during BO compared with that during BC (P < 0.05). For AUC analysis, data were divided into three sections: breakfast to lunch (0–4.5 h), lunch to dinner (5–11 h), and postdinner (11.5–24 h). These analyses revealed differences between trials for all subjective appetite variables between breakfast and lunch (P < 0.01). Fullness was also increased between lunch and dinner during BO compared with that during BC (P < 0.05) (Table 2).

Steady-state exercise and performance test. Total work completed during the performance test was greater during BC (314 ± 53 kJ) than that during BO (300 ± 56 kJ; P < 0.05) (Fig. 3). There was no effect of trial order on exercise performance (P = 0.297). During the 30-min steady-state period, energy expenditure was greater during BO (1407 ± 210 kJ) than that during BC (1330 ± 191 kJ; P < 0.05). Fat oxidation was also greater during BO compared with that during BC (P < 0.05), but there was no difference in CHO oxidation between trials (P = 0.126). Average HR was higher during BO (155 ± 9 bpm) than that during BC (151 ± 8 bpm; P < 0.001) during the steady state but was not different during the performance test (P = 0.397). There were no differences in RPE either during the 30-min steady-state preload (P = 0.464) or the performance test (P = 0.712).

Blood parameters. Plasma glucose (P < 0.05), insulin (P < 0.001), acylated ghrelin (P < 0.001), and GLP-1 (7–36) (P < 0.05) all showed a main effect of time. There were no main effects of trial or interaction effects for plasma glucose (P ≥ 0.201), acylated ghrelin (P ≥ 0.189), or GLP-1 (7–36) (P ≥ 0.056). There was an interaction effect for insulin (P < 0.01), with higher insulin concentrations at 4.5 h during BC than

TABLE 1. CHO, protein, fat, fiber, and water intake over the course of the each trial.

<table>
<thead>
<tr>
<th></th>
<th>Energy (kJ)</th>
<th>CHO (g)</th>
<th>PRO (g)</th>
<th>Fat (g)</th>
<th>Fiber (g)</th>
<th>Water (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breakfast</td>
<td>BC 3005 ± 195</td>
<td>130.3 ± 8.2</td>
<td>19.5 ± 1.2</td>
<td>13.9 ± 0.9</td>
<td>4.5 ± 0.3</td>
<td>625 ± 39</td>
</tr>
<tr>
<td></td>
<td>BO 0 ± 0</td>
<td>0*</td>
<td>0*</td>
<td>0*</td>
<td>0*</td>
<td>625 ± 39</td>
</tr>
<tr>
<td>Lunch</td>
<td>BC 4970 ± 1987</td>
<td>128.5 ± 69.0</td>
<td>44.3 ± 22.8</td>
<td>52.7 ± 20.2</td>
<td>10.2 ± 4.5</td>
<td>814 ± 211</td>
</tr>
<tr>
<td></td>
<td>BO 5804 ± 1878*</td>
<td>148.1 ± 65.1*</td>
<td>50.2 ± 22.2</td>
<td>63.3 ± 23.9*</td>
<td>11.1 ± 4.2</td>
<td>894 ± 207</td>
</tr>
<tr>
<td>Dinner</td>
<td>BC 6359 ± 1631</td>
<td>194.2 ± 49.8</td>
<td>53.6 ± 13.7</td>
<td>55.9 ± 14.3</td>
<td>9.7 ± 2.5</td>
<td>477 ± 121</td>
</tr>
<tr>
<td></td>
<td>BO 5882 ± 1443</td>
<td>179.6 ± 44.1</td>
<td>49.5 ± 12.2</td>
<td>51.7 ± 12.7</td>
<td>9.0 ± 2.2</td>
<td>443 ± 108</td>
</tr>
<tr>
<td>Total</td>
<td>BC 14,424 ± 2255</td>
<td>453.0 ± 80.9</td>
<td>117.4 ± 24.9</td>
<td>122.5 ± 19.7</td>
<td>24.4 ± 5.5</td>
<td>3395 ± 627</td>
</tr>
<tr>
<td></td>
<td>BO 11,685 ± 1893*</td>
<td>327.8 ± 78.3*</td>
<td>99.7 ± 25.0*</td>
<td>115.1 ± 17.6</td>
<td>20.1 ± 5.5*</td>
<td>3335 ± 489</td>
</tr>
</tbody>
</table>

Data are presented as means ± SD.

*Indicates values significantly different from BC (P < 0.05). Please note that the dinner meal was homogeneous in nature; therefore, macronutrient intake is proportional to volume consumed.

PRO, protein.
those during BO ($P < 0.01$), whereas insulin concentrations tended to be higher at 9 h during BO compared with those during BC ($P = 0.073$) (Table 3).

**DISCUSSION**

The primary aim of this investigation was to determine the effect of BO/BC on subsequent energy intake and evening exercise performance. It was found that total work completed over a 30-min cycling performance test was reduced by approximately 4.5% after BO. Although energy intake was increased at lunch, this study also observed no difference in total *ad libitum* energy intake between trials, resulting in a reduced total 24-h energy intake after BO. From a weight management perspective, occasional BO could be used as a viable means of energy restriction in habitual breakfast consumers, although this may slightly impair exercise performance. Further study is required to determine whether BO can be used chronically to assist in long-term weight management.

**TABLE 2.** Time-averaged AUC for each appetite variable.

<table>
<thead>
<tr>
<th></th>
<th>After Breakfast (0–4 h)</th>
<th>After Lunch (5–10.5 h)</th>
<th>After Dinner (11–24 h)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hunger (mm·h⁻¹)</strong></td>
<td>BC 38 ± 15</td>
<td>39 ± 13</td>
<td>44 ± 16</td>
</tr>
<tr>
<td></td>
<td>BO 72 ± 18*</td>
<td>35 ± 16</td>
<td>37 ± 14</td>
</tr>
<tr>
<td><strong>Fullness (mm·h⁻¹)</strong></td>
<td>BC 47 ± 13</td>
<td>56 ± 13</td>
<td>49 ± 17</td>
</tr>
<tr>
<td></td>
<td>BO 12 ± 9*</td>
<td>62 ± 12*</td>
<td>46 ± 15</td>
</tr>
<tr>
<td><strong>DTE (mm·h⁻¹)</strong></td>
<td>BC 45 ± 18</td>
<td>41 ± 13</td>
<td>41 ± 15</td>
</tr>
<tr>
<td></td>
<td>BO 76 ± 21*</td>
<td>35 ± 16</td>
<td>38 ± 11</td>
</tr>
<tr>
<td><strong>PFC (mm·h⁻¹)</strong></td>
<td>BC 47 ± 16</td>
<td>44 ± 12</td>
<td>44 ± 13</td>
</tr>
<tr>
<td></td>
<td>BO 71 ± 20*</td>
<td>43 ± 13</td>
<td>40 ± 15</td>
</tr>
</tbody>
</table>

Data are means ± SD.

*Values are significantly different from BC ($P < 0.05$).

**FIGURE 2**—Subjective sensations of hunger (A), fullness (B), DTE (C) and PFC (D) during BC ($) and BO (○). Data points are means, with vertical error bars representing SEM. White rectangles indicate standard meal feeding; vertical hatched rectangles indicate an *ad libitum* meal; and black rectangles indicate exercise period. All appetite variables showed a main effect of time. †Indicates that values are significantly different between trials ($P < 0.05$).

**FIGURE 3**—Work completed (kJ) during the exercise performance test. The left panel displays mean work completed during BC ($) and BO (○), with vertical error bars representing SD. The right panel displays individual subject’s performance during BC ($) and BO (○). †Indicates that values are significantly different from BC ($P < 0.05$).
The global increase in the prevalence of obesity has coincided with a gradual decline in BC (15), with epidemiological evidence suggesting that those who regularly omit breakfast have a higher BMI than those who regularly consume breakfast (3). However, because of several confounding factors, including variations in activity patterns (6) and dietary profiles (14), there is a lack of causal data linking breakfast eating behavior with energy balance. The results of the current investigation demonstrate that the total energy restricted at breakfast is not accurately compensated for over an acute 24-h period, resulting in a net energy deficit of 2738 kJ. These findings are comparable with those of Levitsky and Pacanowski (22), who found that total energy intake was reduced by approximately 1883 kJ after omitting an ad libitum breakfast meal. Similarly, 7-d consecutive BO was found to reduce energy intake by 670 kJ·d⁻¹ on average compared with 7-d consecutive BC (30). Taken collectively, data from these acute investigations suggest that, contrary to popular belief, BO does not lead to elevated energy intake over the course of the day and, as such, there is potential for BO to be used in successful weight management strategies.

Consistent with previous findings, energy intake at lunch was greater during BO than that during BC (1,19,22,30). After the omission of breakfast, subjective appetite sensations were elevated throughout the morning compared with those when breakfast was consumed (Fig. 2), and accordingly, energy intake at lunch was increased by approximately 16%. However, this modest increase in energy intake (745 ± 604 kJ) only partially compensated for the energy deficit created by the omission of the breakfast meal (3095 ± 195 kJ), and as such, subjects remained in energy deficit throughout the afternoon. Similar to the findings in the current study, Levitsky and Pacanowski (22) reported elevations in hunger after the omission of an ad libitum breakfast meal, leading to increased energy consumption at lunch. Hubert et al. (19) found that reducing breakfast energy intake by 1824 kJ resulted in an average elevation in energy intake at a lunch of 500 kJ. The average compensation at lunch for BO is remarkably consistent between these studies, with the current investigation revealing 24% compensation at lunch compared with the 22% (22) and 26% (19) previously reported.

Concentrations of the orexigenic hormone acylated ghrelin and the anorexigenic hormone GLP-1(7–36) are thought to respond to fluxes in energy balance (8,17) and stimulate a behavioral response. In the current study, the increase in appetite observed throughout the morning period may have caused an increase in energy consumption during the time between breakfast and lunch in free-living conditions as found previously (25). Acylated ghrelin and GLP-1(7–36) were only measured 4 h after BC/BO and immediately before exercise, so the dynamic response of these hormones to feeding may have been missed. After lunch, no differences were observed in subjective appetite sensations, which may suggest no difference in gut hormone concentrations. Accordingly, the appetitive responses to BO seem to be transient and do not influence energy intake after the provision of lunch.

Although there is general agreement in the literature that BO reduces daily energy intake, two investigations contest these findings. Astbury et al. (1) found that the provision of a 1080-kJ breakfast was completely compensated for in the no-breakfast condition at an ad libitum lunch meal. This study was designed primarily to investigate the effect of breakfast on gastrointestinal hormonal regulation of food intake and incorporated a liquid preload between breakfast and lunch that may have influenced energy intake at lunch. In addition, the provision of a low-energy breakfast (10% of daily energy requirements) has previously been shown to be more accurately compensated for at subsequent meals than higher-energy breakfast meals (31). Farschi et al. (11) aimed to investigate whether the timing of BC affected subsequent energy intake. Over a 2-wk period, subjects either consumed cereal and milk at a traditional breakfast time (0700–0800 a.m.) or later in the day (1200–1230 p.m.), which ensured that the energy provided was consistent across both interventions. Energy intake was found to be greater after BO compared with that after BC. This was likely due to the experimental design, which does not necessarily represent typical practice for those using BO as a method of weight management.

It is well documented that consuming breakfast improves exercise performance in the morning compared with omitting breakfast, i.e., exercising in a fasted state (32,33). The current study found that exercise performance was also compromised in the evening after BO in the morning despite consuming lunch 4.5 h before exercise. Eating breakfast is highly encouraged in the literature to maximize CHO stores before competition (38), as glucose availability may be a limiting factor because of glycogen depletion (7). In particular, liver glycogen stores, which are important for blood glucose maintenance during exercise, have been shown to decrease by approximately 40% after an overnight fast (36). Provision of a high-CHO breakfast will help replenish liver glycogen (16) and has been shown to increase muscle glycogen concentrations in the vastus lateralis by 11%–17% (4,37). A recent study reported that 73% of female college athletes regularly omitted breakfast, resulting in suboptimal daily CHO and energy intakes (34). This was also shown in

| TABLE 3. Plasma concentrations of glucose, insulin, acylated ghrelin, and GLP-1(7–36) over the course of the trial during BC and BO. |
|------------------|------------------|------------------|------------------|
|                  | Before Breakfast (0 h) | Before Lunch (4.5 h) | Before Exercise (9 h) |
| Glucose (mmol L⁻¹) | TBC: 5.33 ± 0.18 | TBO: 5.18 ± 0.25 | TBC: 5.27 ± 0.39 |
|                  | 4.89 ± 0.42 | 4.91 ± 0.33 | 5.13 ± 0.67 |
| Insulin (µIU mL⁻¹) | TBC: 1.50 ± 4.4 | TBO: 1.39 ± 3.5 | TBC: 24.2 ± 6.8 |
|                  | 16.1 ± 5.8 | 10.7 ± 4.1 | 30.7 ± 11.5 |
| Acylated ghrelin (pg mL⁻¹) | TBC: 108 ± 114 | TBO: 115 ± 65 | TBC: 92 ± 90 |
|                  | 97 ± 99 | 118 ± 121 | 71 ± 94 |
| GLP-1(7–36) (pmol L⁻¹) | TBC: 7.22 ± 6.06 | TBO: 9.85 ± 9.30 | TBC: 8.51 ± 7.29 |
|                  | 6.55 ± 6.82 | 12.99 ± 12.26 |

Normally and not normally distributed data are presented as means ± SD for consistency. *Indicates that values are significantly different compared with those from baseline (P < 0.05). **Indicates that values are significantly different from BC.
the present study, as CHO intake before exercise was reduced during BO compared with that during BC (148 ± 65 vs 259 ± 73 g), which may have influenced glucose availability and reduced exercise performance. It seems that breakfast may play a central role in meeting the daily CHO requirements for exercising individuals and that BC might be important to maximize exercise performance throughout the day.

Fat oxidation was greater during the 30-min steady-state exercise period in BO. Increasing fat oxidation has been suggested to be beneficial for reducing fat mass and may also promote CHO sparing, potentially improving performance (20). However, there was no difference in CHO oxidation between trials; therefore, it is unlikely that glycogen sparing occurred during BO. Accordingly, energy expenditure was greater during BO, which may be attributable to an increase in dietary-induced thermogenesis induced by greater energy intake at the previous ad libitum lunch meal. An increased contribution of dietary-induced thermogenesis to energy expenditure may also explain the higher HR observed during BO. After food intake, the splanchnic tissues require an increase in blood supply to assist in the digestion and absorption of nutrients. Therefore, during submaximal exercise, an increase in cardiac output is required to meet the oxygen requirements of both the skeletal muscles and splanchnic tissues (39). Another indicator of sympathetic nervous activity is noradrenaline, which has been shown to peak after breakfast, with an attenuated response at subsequent feeding periods (29). After the omission of breakfast, lunch becomes the first meal of the day. It could be considered that the sympathetic nervous response to feeding was greater after lunch during BO compared with that during BC; thus, HR was increased to a greater extent during steady-state exercise. Noradrenaline also increases lipolysis (21) and may explain the elevation in fat oxidation during the steady-state exercise on BO.

A limitation of any research that investigates BO is the difficulty in blinding subjects to the study intervention. In the multifactorial “central governor theory” model of fatigue described by Noakes (28), the subjects’ awareness of the study intervention may lead to an expectation with regard to exercise performance and performance may decline as a result. This may be particularly pertinent with the current study because all subjects were habitual breakfast consumers, so the withdrawal of breakfast in the morning may have produced a particularly strong expectation of reduced performance. This may partially account for the findings in this study.

It has recently been shown that the omission of breakfast over a 6-wk period has a negative effect on physical activity levels, reducing habitual physical activity thermogenesis on average by 1850 kJ d⁻¹ compared with that when breakfast was consumed (2). Physical activity of this nature is difficult to manipulate or avoid because the nutritional intervention seemingly imposes a subconscious restriction on energy expenditure. Incorporating structured exercise into weight management programs may offset the magnitude of this deficit somewhat, provided that adherence to exercise is not affected. Although exercise performance might be important to maximize energy expenditure, the difference in exercise performance observed in the current study had a negligible influence on energy balance. Energy expenditure during the 30-min preload was approximately 80-kJ greater during BO, which was offset by an estimated reduction of energy expenditure of approximately 70 kJ during BO, assuming a cycling efficiency of 20% (18). Therefore, net energy expenditure during exercise was almost identical between trials (2898 ± 307 (BC) vs 2905 ± 307 (BO)) kJ; $P = 0.834$.

In conclusion, the results of the present study demonstrate that occasionally omitting breakfast may be an effective method of reducing energy intake over a 24-h period in habitual breakfast consumers. However, exercise performance may be compromised throughout the whole day after the omission of breakfast in the morning. Therefore, for those concerned with maximizing training and/or competition performance, BO might impair performance or interfere with training adaptation.

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REFERENCES


26. Noakes TD. Fatigue is a brain-derived emotion that regulates the exercise behavior to ensure the protection of whole body homeostasis. Front Physiol. 2012;3(82):113.


