Effect of Carbohydrate Ingestion During Exercise on Post-exercise Substrate Oxidation and Energy Intake

Christopher L. Melby, Kristen L. Osterberg, Alyssa Resch, Brenda Davy, Susan Johnson, and Kevin Davy

Thirteen physically active, eumenorrheic, normal-weight (BMI ≤ 25 kg/m²) females, aged 18–30 years, completed 4 experimental conditions, with the order based on a Latin Square Design: (a) CHO/Ex: moderate-intensity exercise (65% \( \text{VO}_{2\text{peak}} \)) with a net energy cost of ~500 kcals, during which time the subject consumed a carbohydrate beverage (45 g CHO) at specific time intervals; (b) CHO/NoEx: a period of time identical to (a) but with subjects consuming the carbohydrate while sitting quietly rather than exercising; (c) NoCHO/Ex: same exercise protocol as condition (a) during which time subjects consumed a non-caloric placebo beverage; and (d) NoCHO/NoEx: same as the no-exercise condition (b) but with subjects consuming a non-caloric placebo beverage. Energy expenditure, and fat and carbohydrate oxidation rates for the entire exercise/sitting period plus a 90-min recovery period were determined by continuous indirect calorimetry. Following recovery, subjects ate ad libitum amounts of food from a buffet and were asked to record dietary intake during the remainder of the day. Total fat oxidation (exercise plus recovery) was attenuated by carbohydrate compared to placebo ingestion by only ~4.5 g. There was a trend \( (p = .08) \) for a carbohydrate effect on buffet energy intake such that the CHO/Ex and CHO/NoEx energy intakes were lower than the NoCHO/Ex and NoCHO/NoEx energy intakes, respectively (mean for CHO conditions: 683 kcal; NoCHO conditions: 777 kcal). Average total energy intake (buffet plus remainder of the day) was significantly lower \( (p < .05) \) following the conditions when carbohydrate was consumed (CHO/Ex = 1470 kcal; CHO/NoEx = 1285 kcal) compared to the noncaloric placebo (NoCHO/Ex = 1767 kcal; NoCHO/NoEx = 1660 kcal). In conclusion, in young women engaging in regular exercise, ingestion of 45 g of carbohydrate during exercise only modestly suppresses total fat oxidation during exercise. Furthermore, the ingestion of carbohydrate with or without exercise resulted in a lower energy intake for the remainder of the day.

Key Words: exercise, energy intake, carbohydrate, fat, hunger

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Introduction

Regular exercise can have an important impact on energy and macronutrient balance and bodyweight regulation. However, the effects of exercise on energy balance depend on the degree to which an individual compensates for the energy cost of exercise by increasing energy intake, decreasing spontaneous physical activity, or both. Intuitively, an energy deficit produced by an exercise bout would result in an increase in food intake following exercise. While a few studies support this idea (20, 21), there are more reports indicating that an exercise-induced increase in energy expenditure fails to produce a compensatory increase in energy intake in the meal immediately following exercise (11–13, 15–17, 19). Studies have even found that despite large acute exercise energy expenditure, energy intake did not increase throughout the entire day (6), or even the day following exercise (13). These studies indicate that the relative energy intake (energy cost of exercise subtracted from the post-exercise meal[s]) is lower following exercise, possibly more so following higher compared to lower intensity exercise (19). Therefore, it appears that in the short term, increases in exercise energy expenditure are not rapidly compensated for by increases in energy intake.

Most studies that have addressed the impact of exercise on post-exercise food intake have required subjects to exercise in a post-absorptive state. However, because of the well known benefits of carbohydrate consumption on endurance exercise performance (3, 7, 10), a common practice for individuals who engage in long duration exercise is to consume a carbohydrate beverage during exercise in order to maintain normal hydration and glycemia. It is possible that the additional energy from the carbohydrate consumed during exercise could have an additive effect, increasing total energy intake on the exercise day. However, it is also possible the individual could compensate for the additional carbohydrate consumed during exercise by lowering energy intake during subsequent meals (14). This issue has received little research attention.

Anecdotally, some fitness specialists recommend avoidance of carbohydrate beverages during exercise among individuals attempting to lose weight or maintain weight loss. They reason that the additional energy consumed will not only minimize the effect of exercise on energy balance but also that the availability of additional carbohydrates during exercise will minimize fat mobilization and oxidation. While the effects of carbohydrate ingestion during exercise on fat oxidation have been studied (3, 8), less is known about the effect on fat oxidation during the post-exercise recovery period. It is also possible that the availability of exogenous carbohydrate during exercise, as well as the exercise and recovery substrate oxidation rates, could influence macronutrient intake following exercise. King et al. (11) found a positive correlation between the exercise respiratory quotient (RQ, which reflects the relative contributions to energy expenditure of fat, carbohydrate, and protein oxidation) and the food quotient (FQ, which reflects the relative contributions of fat, carbohydrate, and protein to energy intake) during post-exercise meals. In support of this finding, Verger et al. (20) found that high intensity compared to low intensity exercise was associated with a greater proportion of the post-exercise energy intake from carbohydrates.

To date, the effect of exercise, with and without carbohydrate consumption, on exercise and recovery macronutrient oxidation and on post-exercise energy intake has not been adequately examined. Therefore, the purpose of this study was to investigate the effects of consuming a carbohydrate beverage versus placebo during
moderate-intensity, long-duration exercise on exercise and post-exercise fat and carbohydrate oxidation, and on post-exercise energy and macronutrient intake. We also determined if the macronutrient composition of the foods selected following exercise was related to the macronutrient oxidation rates during exercise and recovery.

Methods

Subject Selection

Thirteen physically active, healthy, eumenorrheic females between the ages of 18 and 30 were selected for the study. All subjects engaged in three to five endurance exercise sessions (running/biking) per week for at least the previous 6 months and exhibited a peak oxygen uptake (VO\textsubscript{2peak}) of at least 35 ml\textsuperscript{-1} \cdot kg\textsuperscript{-1} \cdot min. All subjects were of normal weight based on a body mass index (BMI) < 25 and were weight stable (no more than 2-kg weight fluctuation during the past 6 months). Additionally, subjects had no history of chronic health problems, were non-smokers, and were not taking any medications that could influence metabolic rate, appetite, or substrate oxidation. Approval from the Colorado State University Human Research Committee was granted prior to the beginning of the study. Subjects were informed both orally and in writing of the testing methods and procedures utilized in the study, as well as the benefits and health risks associated with the experimental protocol. Subjects voluntarily signed a consent form prior to participation.

Experimental Design

Each subject completed four different treatment conditions, with the treatment order based on a Latin Square design: (a) CHO/Ex: moderate intensity exercise (65% VO\textsubscript{2peak}) for a time sufficient to expend a net 500 kcals, during which time the subject consumed a carbohydrate beverage at specific time intervals; (b) CHO/NoEx: a period of time identical to (a) but subjects sat quietly in a comfortable chair during which time they consumed a carbohydrate beverage at specific time intervals; (c) NoCHO/Ex: same exercise protocol as condition (a) during which time subjects consumed a non-caloric placebo beverage; and (d) NoCHO/NoEx: same as the no-exercise condition (b) but subjects consumed a non-caloric placebo beverage. The exercise duration was determined by calculating the caloric equivalent per liter of oxygen per minute at 65% VO\textsubscript{2peak} for each subject. Resting oxygen consumption was then subtracted from 65% VO\textsubscript{2peak} to determine net caloric expenditure per minute.

Each of the four conditions was completed during the follicular phase of the subjects’ menstrual cycle. Because a 2-day washout period was required between each experimental condition, only two conditions could be completed during each menstrual cycle, with the remaining two conditions completed during identical days of the following month’s cycle. The four testing conditions were completed over the course of two menstrual cycles to insure that the testing outcomes were not affected by changes in energy expenditure and substrate oxidation that may occur during different phases of the menstrual cycle. In addition, subjects were instructed to refrain from any physical activity for a minimum of 24 hours prior to each testing condition.
**Resting Metabolic Rate**

Resting metabolic rate was measured to help establish each subject's daily energy requirements. Each subject arrived at the lab the morning following a 12-hour overnight fast and before engaging in any type of physical activity. Indirect calorimetry (CPX Express, MedGraphics) was used to determine resting metabolic rate (RMR). Subjects were familiarized with the procedure, while the metabolic cart was calibrated with known gas concentrations. Subjects were seated in a comfortable chair with a mouthpiece and noseclip, while resting \( \text{VO}_2 \) and \( \text{VCO}_2 \) values were obtained by open circuit spirometry. The deWeir equation (4) was used to convert the gas exchange values into kilocalories expended.

**Peak Oxygen Consumption**

Peak oxygen consumption (\( \text{VO}_{peak} \)) was determined by using a Monark bicycle ergometer (Stockholm) and a progressive maximal workload protocol. Oxygen consumption was measured by indirect calorimetry using a CPX Express (Medical Graphics, St. Paul, MN). Heart rate was monitored during the test using a wireless heart rate monitor (Polar).

**Dietary Protocol**

Prior to participation, a research dietitian instructed each participant on how to properly complete a 3-day food intake record. The food records were analyzed using the Food Intake Analysis System (FIAS; University of Texas Health Sciences Center, Houston) to determine each subject’s usual energy and macronutrient intake. Prior to participation in the four experimental conditions, a questionnaire to determine food preferences and acceptability was also administered to determine any foods that the subjects did not enjoy as well as to determine any self-identified food allergies. In addition, subjects completed the Eating Attitudes Test (EAT-26) prior to participation to screen for eating disorders (5).

Two days prior to each testing condition, subjects were provided with outpatient-standardized meals prepared in the dietary kitchen at Colorado State University. These meals were designed to keep subjects in energy balance with a macronutrient composition of 60% carbohydrate, 25% fat, and 15% protein. Energy content of meals was based on RMR 3 1.5 two days prior to testing and RMR 3 1.3 the day before testing to account for the lack of exercise the day before any testing, corresponding to a moderate activity day and a very light activity day, respectively. Subjects were instructed that all foods provided were to be consumed on each outpatient day. Given the imprecision in determining energy balance over the short term, for both outpatient days, subjects were provided with additional food modules (with the same macronutrient distribution as the entire day’s food), with the option of consuming up to 200 additional kcal, should they feel a need for more food on these days. Subjects were instructed to return any uneaten food, and few of the subjects consumed the additional modules. Subjects were allowed to drink water ad libitum throughout each outpatient day.

On the morning of each testing condition, subjects were provided with a standardized breakfast designed to provide subjects with 25% of daily energy intake. The macronutrient composition of the breakfast was identical to that of the
outpatient diets and the modules. Following breakfast, subjects were provided with a liquid snack (Gatorpro, Quaker Oats, Barrington, IL; single serving: 355 ml = 350 kcal, 59 g CHO, 6 g fat, and 17 g protein) based on body weight (4 ml/kg). Subjects had unlimited access to water in the period between breakfast and afternoon testing.

**Testing Protocols**

At 0700 hours on the morning of each testing condition, subjects reported to the Nutrition and Metabolic Fitness Laboratory at Colorado State University. Subjects were weighed, given a standardized breakfast, which they ate on site, then provided a snack to be consumed at 1000 hours. Subjects were then released and instructed to refrain from any physical activity until their return in the afternoon.

At 1300 hours, subjects returned to the laboratory and a 15-min period of indirect calorimetry was completed in a comfortable chair with the subject sitting quietly to obtain pre-exercise values. Following this 15-min period of resting energy expenditure measurement, subjects completed one of the four experimental conditions. On the 2 exercise days, subjects began with a 5-min warm up on the bicycle ergometer. By the end of the 5th minute, subjects achieved 65% of \( \text{VO}_{2\text{peak}} \). Subjects then exercised for a period of time sufficient to produce a net cost of approximately 500 kcal (total exercise energy expenditure minus resting energy expenditure). During the exercise session, subjects wore a respiratory facemask covering their nose and mouth. Continuous indirect calorimetry insured the exercise intensity was maintained close to 65% \( \text{VO}_{2\text{peak}} \) over the entire exercise bout. Subjects consumed a total of either 750 ml of carbohydrate or a placebo beverage during each exercise session (200 ml at 15, 30, and 45 min, and the final 150 ml at 60 min). During beverage consumption, the respiratory facemask was removed for 3 min while the subject continued to exercise.

Upon completion of exercise, the subjects were moved from the cycle ergometer to a comfortable chair, and indirect calorimetry was continued for the first 10 min of exercise recovery. After this brief period, subjects completed a hunger questionnaire, in which they were asked to rate the magnitude of their desire to eat based on a visual analog scale, and were permitted to void and drink water. During this 5-min period, the gas analyzers were recalibrated, and subjects returned to complete the last 75 min of the 90-min post-exercise period of indirect calorimetry. During the non-exercise control conditions, the protocol was identical to the exercise sessions except, rather than exercising, the subjects sat quietly for the same length of time as the exercise and recovery periods.

Upon completion of the post-exercise recovery session (90 min following exercise), subjects were again asked to complete the hunger questionnaire, then presented with a food buffet composed of entrees, side dishes, and beverages. Total energy intake as well as carbohydrate, protein, and fat consumption from the buffet were determined for each individual.

**Carbohydrate Beverages**

During exercise, subjects received either a sports drink containing 6% carbohydrate and electrolyte solution (Gatorade, Barrington, IL), with the consumption volume based on 1.5 ml of fluid and 0.09 g of carbohydrate per net kilocalorie expended during exercise, designed to meet current American College of Sports Medicine recommendations (2) for both fluid (600–1200 ml per hour during exercise) and
carbohydrate intake (30–60 g per hour). We standardized the fluid and carbohydrate intake to energy expenditure rather than time, given that the net exercise energy expenditure goal was the same for all subjects, but the exercise duration at an intensity of 65% $\dot{V}O_{2max}$ varied between subjects. Because the target net cost of exercise was 500 kcal for each subject, a total of 750 ml and 45 g CHO was provided for the CHO/Ex condition, and 750 ml of a placebo beverage containing no carbohydrate was provided for the NoCHO/Ex condition. For the no-exercise control conditions, subjects were provided with only 225 ml of fluid in the form of a 20% carbohydrate drink containing a total of 45 g of carbohydrate (Gatorlode, Quaker Oats, Barrington, IL) or 225 ml of placebo. Each beverage was given at the same 15-min intervals as the exercise conditions. Less fluid was provided during the no-exercise control conditions to help minimize over-hydration during the sitting protocol in which the fluid losses by sweating were minimal.

**Post-exercise Food Intake**

Following each experimental condition, subjects were presented with a buffet composed of entrees, side dishes, and beverages. Subjects were told they could eat whatever foods and amounts they desired in a 30-min period but were not informed that this test meal was to determine the effect of prior exercise and carbohydrate beverage consumption on their energy and macronutrient intake. The position of each item on the buffet was identical for every testing session. A radio and magazine were present in the room to provide a pleasant eating environment.

To determine how much of each item from the food buffet was eaten for every subject, the weights of all of the food items were measured before the subject began eating. Upon completion of the buffet, all food was weighed again to determine the amount of each food consumed by the subject. Analysis of each subject’s food selection was accomplished using FIAS to establish the total energy intake as well as the portions of carbohydrate, protein, and fat intake.

Upon finishing consumption of food from the buffet, subjects left the laboratory but were asked to record whatever foods they chose for the remainder of the day. One study subject lost her post-buffet food records for all four conditions, and 5 subjects failed to provide post-buffet energy intake data for at least one of the four conditions. Thus, the post-buffet food consumption data are limited to 7 subjects with complete food records for all four conditions.

**Data Analysis**

A two-way repeated measures ANOVA was used to analyze (exercise/no exercise by carbohydrate/no carbohydrate) rates of fat and carbohydrate oxidation, total fat and carbohydrate oxidation, total energy and macronutrient intake, as well as subjective rates of hunger and satiety. Where appropriate, paired t tests were performed to examine differences in response to two specific treatment conditions of interest. Statistical significance was set at $p < .05$.

**Results**

The physical characteristics of the 13 subjects are shown in Table 1. The subjects were normal weight, physically active young women, with an average peak $\dot{V}O_2$ of approximately 40 ml · kg$^{-1}$ · min$^{-1}$. Body weights were similar for the subjects across
Analyses of their self-reported 3-day dietary records revealed a mean energy intake of 1901 ± 154 kcal, with a macronutrient distribution of 56% carbohydrate, 27% fat, and 17% protein.

The subjects’ characteristics during the exercise and quiet sitting sessions for the four conditions are provided in Table 2. The average time necessary for the subjects to achieve the goal of a net exercise energy expenditure of 500 kcal was approximately 75 min. The actual relative exercise intensity was close to the goal of 65% of peak VO$_2$ (CHO/Ex = 66.0%, NoCHO/Ex = 66.2%); the average net cost of the two exercise sessions was close to the goal of 500 kcal, and did not differ between exercise conditions (CHO/Ex = 514 kcal; NoCHO/Ex = 517 kcal).

Table 1 Physical Characteristics of Study Participants ($N = 13$)

<table>
<thead>
<tr>
<th>Variable</th>
<th>X + SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>23.0 ± 0.8</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>168.4 ± 1.4</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>61.0 ± 0.4</td>
</tr>
<tr>
<td>BMI (kg/m$^2$)</td>
<td>21.6 ± 0.2</td>
</tr>
<tr>
<td>Peak VO$_2$ (L)</td>
<td>2.86 ± 0.07</td>
</tr>
<tr>
<td>Peak VO$_2$ (ml/kg/min)</td>
<td>39.6 ± 0.9</td>
</tr>
<tr>
<td>Peak RER</td>
<td>1.2 ± 0.01</td>
</tr>
<tr>
<td>Peak heart rate</td>
<td>181.9 ± 3.2</td>
</tr>
</tbody>
</table>

Note. BMI = Body Mass Index; RER = respiratory exchange ratio.

Table 2 Mean Characteristics of the 13 Subjects for Each of Four Testing Conditions ($X ± SEM$)

<table>
<thead>
<tr>
<th>Variable</th>
<th>CHO Exercise</th>
<th>CHO No Exercise</th>
<th>NoCHO Exercise</th>
<th>NoCHO No Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight</td>
<td>61.0 ± 1.0</td>
<td>60.9 ± 0.9</td>
<td>61.1 ± 1.0</td>
<td>61.0 ± 0.8</td>
</tr>
<tr>
<td>VO$_2$ (ml/min)</td>
<td>1596 ± 39</td>
<td>218 ± 4</td>
<td>1603 ± 37</td>
<td>214 ± 7</td>
</tr>
<tr>
<td>Percent peak VO$_2$</td>
<td>66.0 ± 0.6</td>
<td>9.0 ± 0.2</td>
<td>66.3 ± 0.5</td>
<td>8.9 ± 0.4</td>
</tr>
<tr>
<td>Time (min)</td>
<td>75.5 ± 2.2</td>
<td>75.8 ± 2.3</td>
<td>75.5 ± 2.2</td>
<td>75.8 ± 2.3</td>
</tr>
<tr>
<td>METs</td>
<td>7.33 ± 0.18</td>
<td>1</td>
<td>7.49 ± 0.17</td>
<td>1</td>
</tr>
<tr>
<td>Net energy cost</td>
<td>514 ± 7</td>
<td>0</td>
<td>517 ± 6</td>
<td>0</td>
</tr>
</tbody>
</table>

Note. MET = metabolic equivalent expressed as a multiple of resting VO$_2$. 

all four conditions. Analyses of their self-reported 3-day dietary records revealed a mean energy intake of 1901 ± 154 kcal, with a macronutrient distribution of 56% carbohydrate, 27% fat, and 17% protein.
Exercise Period Versus Control Condition of Quiet Sitting

Figure 1 shows the oxygen consumption averaged over 15-min intervals during each of the two exercise (CHO/Ex and NoCHO/Ex) and the two no-exercise conditions (NoCHO/Ex and NoCHO/NoEx). Oxygen consumption was approximately 7.5 times higher during exercise compared to no-exercise conditions (i.e., 7.5 METS), with an obvious main effect of exercise, but no effect of carbohydrate consumption and no carbohydrate-by-exercise interaction. These data clearly indicate success in matching the intensity of the two exercise conditions. The data also demonstrate the similarities in resting \( \dot{V}O_2 \) for the two no-exercise conditions.

Figure 2 shows the respiratory exchange ratio (RER) data averaged over the 15-min intervals during the exercise and no-exercise conditions. Not surprisingly, there was a significant exercise effect, with the mean RER value combined for the two exercise conditions significantly higher compared to the mean for no-exercise conditions. There was not a significant carbohydrate effect, indicating that within
each of the exercise conditions and no-exercise control conditions, respectively, consumption of the carbohydrate beverage did not affect substrate utilization.

**Exercise Versus No-Exercise Recovery Period**

The 90-min post-exercise recovery RER data are shown in Figure 3. There was a significant interaction of carbohydrate intake and exercise on recovery RER. The RER averaged across the two exercise conditions was significantly lower than the mean RER for the two no-exercise conditions. Mean RER was higher for the two carbohydrate conditions relative to no carbohydrate intake. The significant interaction was the result of the significantly higher RER for the CHO/NoEx condition relative to the other three conditions. The recovery RER in the CHO/Ex condition was significantly higher than that of the NoCHO/Ex, but the magnitude of the difference was much smaller than the difference between CHO/NoEx and NoCHO/NoEx. These data suggest that exercise dampened the reliance on carbohydrate oxidation during recovery, even in the face of greater carbohydrate availability resulting from carbohydrate consumption during exercise.

**Total Energy Expenditure and Macronutrient Oxidation**

The total energy expenditure including exercise plus recovery was obviously much higher for the two exercise conditions (CHO/Ex = 703 ± 15 kcal; NoCHO/Ex = 701 ± 7 kcal) relative to the no-exercise conditions (CHO/NoEx = 180 ± 4 kcal; NoCHO/NoEx = 177 ± 6 kcal).

The RER data during exercise and recovery were used to calculate the total amounts of carbohydrate and fat oxidized for the combined exercise or quiet control sitting sessions, and their respective recovery periods. As shown in Figure 4, total carbohydrate oxidation was significantly higher for the two EX compared to the two NoEx conditions (p < .0001), and for the two CHO compared to NoCHO conditions (p = .05). There was no EX by CHO interaction. Total fat oxidation (Figure 5) was

![Figure 3 — Mean respiratory exchange ratio averaged across the exercise and no-exercise control periods for each of the four testing conditions](image)
also highest averaged across the two EX conditions ($p < .0001$), with carbohydrate consumption during exercise attenuating total fat oxidation by a modest amount (4.5 g). Paired $t$ tests revealed no significant differences in total fat oxidation and total carbohydrate oxidation between CHO/Ex and NoCHO/Ex, respectively.

**Post-exercise Energy and Macronutrient Intake**

Subjects were asked to rate their subjective feelings of hunger 10 min following exercise and again 90 min after exercise, just prior to the test meal from the food buffet. There was a main effect of exercise on hunger 10 min following exercise or sitting, with subjects rating their desire to eat as significantly weaker following

![Figure 4](image1.png)

**Figure 4** — Mean total carbohydrate oxidation (g) for the entire 180-min testing period (pre-exercise, exercise/control, recovery) for each of the four testing conditions.

![Figure 5](image2.png)

**Figure 5** — Mean total fat oxidation (g) during the entire 180-min testing period (pre-exercise, exercise/control, recovery) for each of the four testing conditions.
exercise compared to the no-exercise conditions. However, there were no main effects of exercise or carbohydrate beverage on subject’s ratings of hunger 90 min following exercise or sitting, just prior to eating from the food buffet. Subjects were allowed to eat ad libitum from the buffet, which contained a wide variety of entrees, side dishes, beverages, and desserts. Table 3 shows the mean energy and macronutrient intake for the 13 subjects for each of the four conditions. Despite slightly higher mean energy intakes for the exercise compared to no-exercise conditions (mean for exercise conditions: 758 kcal; no-exercise conditions: 702 kcal), the main effects of exercise did not reach statistical significance, and there was no CHO-by-Ex interaction. These data clearly show that the subjects did not compensate for energy expended in exercise by increasing their ad libitum energy intakes as early as 90 min post-exercise. There was a trend ($p = .08$) for a carbohydrate effect on buffet energy intake such that the CHO/Ex and CHO/NoEx energy intakes were lower than the NoCHO/Ex and NoCHO/NoEx energy intakes, respectively (mean for CHO conditions: 683 kcal; NoCHO conditions: 777 kcal). There were no differences in ad libitum macronutrient intake from the buffet, in the weight of the food ingested, or in the energy density of the food consumed for any of the four conditions.

Table 4 contains data for energy and macronutrient intakes based on subject records of their food and beverage intake from the time they finished the buffet until they retired to bed that same evening. (For repeated measures analysis, data are required for all conditions for each subject, so these analyses are based on only the 7 subjects who completed records for all four conditions.) There was no exercise effect, but there was a carbohydrate effect ($p < .05$) on post-buffet energy intake such that energy intake was lower for CHO/Ex and CHO/NoEx compared to NoCHO/Ex and NoCHO/NoEx (mean for CHO conditions: 644 kcal; mean for NoCHO conditions: 917 kcal). Figure 6 shows that when the buffet and the post-buffet energy intakes were summed across the two carbohydrate conditions versus the two no-carbohydrate conditions, there was no exercise effect, but there was a significant

Table 3  Mean Energy and Macronutrient Intake for Subjects ($N = 13$) Ingesting Food Ad Libitum From a Buffet 90-Min Post Exercise

<table>
<thead>
<tr>
<th>Variable</th>
<th>CHO</th>
<th>NoCHO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exercise</td>
<td>No Exercise</td>
</tr>
<tr>
<td>Energy ($^\dagger$)</td>
<td>735 ± 88</td>
<td>630 ± 46</td>
</tr>
<tr>
<td>CHO (g/d)</td>
<td>105.5 ± 13.6</td>
<td>90.2 ± 9.3</td>
</tr>
<tr>
<td>CHO (% kcal)</td>
<td>58.7 ± 3.6</td>
<td>55.4 ± 4.0</td>
</tr>
<tr>
<td>Fat (g/d)</td>
<td>20.8 ± 3.2</td>
<td>18.1 ± 2.1</td>
</tr>
<tr>
<td>Fat (% kcal)</td>
<td>23.5 ± 2.5</td>
<td>26.0 ± 2.9</td>
</tr>
<tr>
<td>Protein (g/d)</td>
<td>34.4 ± 4.4</td>
<td>29.2 ± 3.3</td>
</tr>
<tr>
<td>Protein (% kcal)</td>
<td>17.8 ± 1.7</td>
<td>18.6 ± 1.8</td>
</tr>
<tr>
<td>Food weight (g)</td>
<td>614 ± 74</td>
<td>564 ± 59</td>
</tr>
<tr>
<td>Energy density</td>
<td>1.25 ± .15</td>
<td>1.25 ± .47</td>
</tr>
</tbody>
</table>

Note. There were no significant main effects or interactions. $^\dagger$Main effect of carbohydrate intake, $p = .08$. 
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Main effect of carbohydrate ($p < .05$; CHO conditions: 1388 kcal; No-CHO conditions: 1679 kcal). Carbohydrate (196 vs. 233 g) and protein (65 vs. 78 g) intakes were lower for the CHO compared to No-CHO conditions ($p < .05$), but the lower fat intake for the CHO conditions (38 vs. 48 g) did not reach statistical significance.

Relative energy intake was calculated as the total 24-hour energy intake (breakfast, snack, carbohydrate beverage, buffet test meal, and post-buffet intake) minus the energy cost of exercise. Thus, due to the lack of exercise for the non-exercise conditions, relative energy intake is identical to absolute energy intake for the CHO/NoEx and NoCHO/NoEx conditions. Figure 7 shows that subjects failed to adequately compensate for the energy cost of exercise in the short term. That is, on the day of the exercise bout, the study participants did not increase their energy intake to balance the energy cost of exercise.

Macronutrient selection (based on calculated food quotients) from the post-exercise food buffet, and from foods consumed during the remainder of the day, were unrelated to the RER values during exercise and sitting, and during the recovery period.

**Discussion**

The present study was designed to investigate the effects of consumption of a carbohydrate drink compared to consumption of a noncaloric placebo beverage, during exercise of moderate intensity (65% $\dot{V}O_2peak$) on substrate oxidation, and on post-exercise energy and macronutrient intakes in physically active women. There are three findings of this study that warrant discussion: (a) Relative energy intake...
(total energy intake minus the energy cost of exercise) is significantly lower during the 24-hour period, which included exercise compared to the non-exercise days, regardless of whether or not a carbohydrate beverage is consumed during exercise; (b) consumption of a carbohydrate compared to a placebo beverage, with or without exercise, may cause individuals to compensate for the energy provided in the carbohydrate beverage by decreasing EI for the remainder of the day; and (c) consumption of a carbohydrate compared to a placebo beverage during exercise does not alter substrate utilization during exercise at 65% VO$_{2\text{max}}$ and results in only modest increases in carbohydrate oxidation and decreases in fat oxidation during recovery.

Some studies (15–17), but not all (20, 21), have shown that exercise dampens the desire to eat immediately following cessation of exercise. In a similar fashion,
our subjects reported a significantly weaker desire to eat immediately following the exercise session compared to the controlled sitting condition, but by 90 min post-exercise, the subjective ratings of hunger were similar to the sitting conditions. Unlike our study, most others have examined energy intake/compensation during a single meal following exercise. However, Gilsenan et al. (6) found that even with a substantial increase in energy expenditure induced by exercise, subjects did not increase their energy intake throughout the entire day. In a similar fashion, the subjects in our study did not adequately compensate for the additional 500 kcal of energy expenditure from exercise by increasing their energy intake in the meals following exercise. However, this short-term uncoupling of energy intake from energy expenditure induced by exercise is unlikely to continue over the long term. In a cross-sectional study, Maughan and Aulin (18) found higher energy intakes in physically active compared to inactive individuals, reinforcing the fact that energy intake and expenditure are tightly coupled over time in weight-stable individuals. However, it remains unclear from our study to what extent the subjects compensated the following day(s), and over what timeframe any compensation occurred. These are important questions for future studies.

There was a trend ($p = .08$) for lower ad libitum energy intake from the food buffet following consumption of 45 g of carbohydrate with or without exercise (683 kcal) compared to the placebo conditions (777 kcal). When examining the entire post-exercise period (food buffet plus intake during the rest of the day), the mean total energy intakes for the two carbohydrate conditions were significantly lower than the mean total energy intakes for the two conditions when the noncaloric placebo beverage was consumed (mean of the two CHO conditions = 1388 kcal; mean of the two NoCHO conditions = 1679 kcal). When the energy intake of the 45 g of carbohydrate from the sports drink was included in the total energy intake, differences between CHO and NoCHO conditions were attenuated by 180 kcal and were no longer significant. These data suggest that in response to ingestion of the carbohydrate beverage, whether they exercised or not, subjects compensated by reducing their total energy intake during the remainder of the day. King et al. (14) have also reported such energy compensation following carbohydrate ingestion during exercise. They found that a sucrose-containing beverage consumed during exercise compared to an artificially sweetened placebo consumed during exercise, suppressed post-exercise energy intake by approximately the energy content of the drink itself. They suggested that exercise might prime the body to respond sensitively to even modest nutritional manipulations. However, we found the energy compensation in response to the carbohydrate drink, to be even greater on the non-exercise than the exercise day, although this difference was not statistically significant. Together, these studies suggest that consumption of carbohydrate during exercise does not increase the caloric intake of the individual for the day owing to compensatory reductions in energy intake. Neither our study, nor that of King et al. (14), examined possible mechanisms for the energy compensation. This issue obviously warrants attention in future studies.

As has been seen in previous studies in which subjects exercised at 65–75% of $\dot{V}O_{2\text{max}}$ (3), the ingestion of carbohydrate compared to placebo during exercise did not increase the rate of carbohydrate oxidation and decrease the rate of fat oxidation during the exercise bout itself. However, during the exercise recovery period, differences in macronutrient oxidation rates were seen between carbohydrate and placebo conditions. Few studies have investigated the effect of carbohydrate consumption
during exercise on substrate oxidation rates during the recovery period from exercise, but Calles-Escandon et al. (1) have shown that a pre-exercise carbohydrate feeding is associated with a decreased lipid oxidation rate during 60 min of post-exercise recovery. Including the exercise and recovery periods, the ingestion of 45 g of carbohydrate during exercise at 65% peak VO₂ reduced fat oxidation by only 4.5 g over the 2.5–3-hour period. The possibility of cumulative effects of a small difference in fat oxidation on long-term body weight regulation is unknown. It is daily fat balance, which also includes fat intake, that is the issue in body fat accumulation. Thus without using highly accurate measures of total 24-hour substrate oxidation rates and energy and macronutrient intakes, the implications of a small difference in fat oxidation are unclear. Neither the exercise or recovery macronutrient oxidation rates for the two exercise conditions were related to the subjects’ macronutrient selections during the test meal or during the remainder of the day.

Several caveats warrant mention. We used indirect calorimetry to calculate substrate oxidation rates without urinary nitrogen determinations to estimate protein oxidation. While protein oxidation contributes little to resting and exercise energy expenditure, it should be recognized that the calculated fat and carbohydrate oxidation rates for the study subjects are slightly overestimated. However, it is doubtful that protein oxidation rates would differ much between the two exercise conditions, the most important pair-wise comparison of substrate oxidation rates among the four conditions. Another limitation is that the energy intake during the hours following the food buffet was based on self-reportage in a reduced number of study subjects. However, even with only 7 subjects, the reduction in reported energy intake following carbohydrate consumption is statistically significant owing to the consistent subject response. Note that energy expenditure was not measured during this period for any of the four conditions. It is possible that following the two exercise conditions, spontaneous activity was reduced in comparison to the two control conditions, which would affect the differences in relative intake among the conditions. Future studies should address these caveats by determining energy intake via observation rather than self-report during the days following exercise and carbohydrate ingestion, and should also determine energy expenditure during this same time period.

In conclusion, this study suggests that in moderately trained women during exercise at 65% peak VO₂, carbohydrate ingestion does not significantly affect the rate of CHO and fat oxidation (as measured by indirect calorimetry) during ~75 min of exercise, and only slightly increases the reliance on CHO oxidation for fuel during recovery. Also, carbohydrate ingestion during exercise only modestly suppresses fat oxidation during the entire exercise and recovery period.

Results from this study also suggest that CHO beverage consumption with or without exercise in young women may result in compensatory decreases in energy intake when food intake is measured following exercise.

Finally, subjects fail to adequately compensate for the energy cost of exercise on the day of the exercise bout.

References


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