The Influence of Post-exercise Macronutrient Intake on Energy Balance and Protein Metabolism in Active Females Participating in Endurance Training

Brian D. Roy, Katherine Luttmer, Michael J. Bosman, and Mark A. Tarnopolsky

The purpose of this investigation was to determine the influence of post-exercise macronutrient intake on weight loss, protein metabolism, and endurance exercise performance during a period of increased training volume. Ten healthy young female endurance athletes performed 4 60-min bouts of cycle ergometry at ~65% of VO$_{2peak}$ on 4 days (day 1, 3, 4, and 6) during 2 separate 1-week periods. On day 7, participants performed a ride to exhaustion at ~75% of VO$_{2peak}$. One of the 7-day periods served as a control condition, where a placebo beverage was consumed following the exercise bouts on days 1, 3, 4, and 6 (CON). During the other 7-day protocol (POST), participants consumed a pre-defined formula beverage with added carbohydrate following the exercise bouts on days 1, 3, 4, and 6. Energy intake and macronutrient proportions were the same between the 2 trials; the only difference was the timing at which the macronutrients were consumed. Calculated fat oxidation was greater during exercise on day 6 during POST as compared to CON ($p < .05$). Glucose and insulin concentrations were significantly higher ($p < .05$) following exercise during POST as compared to CON. There was a trend ($p = .06$) for nitrogen balance to be greater on days 5 and 6 with POST as compared to CON. Time to exhaustion during exercise on day 7 was longer during POST as compared to CON ($p < .05$). POST resulted in a maintenance of body weight during the 7-day protocol, while there was a significant ($p < .05$) reduction with CON. It was concluded that post-exercise macronutrient intake following endurance exercise can attenuate reductions in body weight and improve nitrogen balance during 7 days of increased energy expenditure. Importantly, post-exercise supplementation improved time to exhaustion during a subsequent bout of endurance exercise.

Key Words: nitrogen balance, post-exercise nutrition, exercise performance

Introduction

The importance of adequate carbohydrate (CHO) and energy intake to optimize endurance exercise performance has been a focus of investigation for many years.

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Historically, a high carbohydrate diet, which maximizes muscle glycogen content, was established as improving endurance exercise performance (1, 11, 18). There is also evidence to suggest that the timing of macronutrient intake can also influence exercise metabolism. For example, it has been shown by a number of laboratories that nutritional intake soon after endurance exercise can maximize the rate of muscle glycogen resynthesis (12, 19, 20, 32). In addition, the consumption of carbohydrate immediately following resistance exercise can increase the rate of muscle glycogen resynthesis (29), decrease the amount of myofibrillar protein degradation (30), increase whole body protein synthesis (28), and potentially increase muscle protein synthesis (30). It has been suggested that given an adequate intake of carbohydrate over a 24-hour period (7–10 g · kg\(^{-1}\)), muscle glycogen concentration should be optimal for exercise performance (7). However, it remains unclear if such consumption is adequate for individuals who partake in multiple sessions of physical activity in a given 24-hour period.

The macronutrient composition of the diet and training state appear to be important in the regulation of protein oxidation, specifically branched-chain amino acid oxidation. Oxidation of the branched-chain amino acids (BCAA) is regulated by the activity of branched-chain 2-oxoacid dehydrogenase (BCOAD) (6). A chronic high protein diet leads to an increase in BCOAD activity in the liver, while a chronic high carbohydrate diet results in a reduction in BCOAD activity (5, 16, 17). Endurance training also alters the activity of this enzyme. Specifically, training leads to a reduction in the percent activation of BCOAD in skeletal muscle during exercise (at the same power output as before training), which has been correlated to a reduction in leucine oxidation and urea excretion (23). Ultimately, a decrease in BCOAD activity must occur for a reduction in protein oxidation to take place, which would then contribute to an improved nitrogen balance. Clearly, the interaction of both dietary intake and training state are influential in the control of protein metabolism and nitrogen balance.

Alterations in protein metabolism, such as increases in protein synthesis and reductions in protein degradation, could have positive effects on whole body nitrogen balance, since the current Canadian RNI for protein has been demonstrated to be inadequate for elite endurance athletes (33), and many female athletes have characteristically low protein (24) and energy (21) intakes. Alterations in the timing of nutrients may be a possible strategy in maintaining a more positive nitrogen balance, despite the increased energy expenditure associated with endurance training.

Therefore, the purpose of the current study was to determine the effects of the timing of macronutrient intake on indices of protein metabolism, energy balance, and endurance exercise performance in recreationally trained females exposed to a significant increase in training load (metabolic stress).

**Methods**

**Subjects**

Ten young active females were recruited and screened to ensure they were healthy for participation in the study. All participants participated regularly in some form of endurance activity (3 d · wk\(^{-1}\), 45 min · d\(^{-1}\)) and were considered recreationally active. Prior to inclusion in the investigation, a cycling \(\dot{V}O_2\) \(\dot{sp}\) test was performed with a minimum requirement of at least 40 ml · kg\(^{-1}\) · min\(^{-1}\) for inclusion...
in the investigation. The experimental procedures, risks, and benefits were explained to each subject before written consent was obtained and after approval from the McMaster University Human Ethics Committee. Subject characteristics are described in Table 1. Six of the subjects were taking tri-phasic oral contraceptives.

All females were eumenorrheic, with a normal cycle length of 27–33 days. In addition, all of the tests were conducted during the mid-follicular phase of their cycle (days 4–11). Upon acceptance into the investigation, the participants were required to maintain their current level of training throughout the entire study.

Measurements of \( \dot{V}O_{2\text{peak}} \) were obtained during progressive cycling to fatigue, which were completed at least 1 week prior to the first exercise test as previously described (25). All bouts of exercise were performed on an electrically braked cycle ergometer (Quinton 870, Excalibur Sport, Netherlands). Ventilatory and gas exchange measures were determined using an open-circuit system, which has been previously described (25). These values were used to determine the relative power outputs used for the submaximal tests. Relative power output estimations were verified with a 10-min cycling test at the predicted workload. To further familiarize the participants with the testing protocol and exercise intensities, a ride to exhaustion was performed at 75\% \( \dot{V}O_{2\text{peak}} \) on the morning following the \( \dot{V}O_{2\text{peak}} \) test. From these initial rides, target heart rates were determined for the exercise intensities that would be used for the subsequent performance rides.

Measurements of body composition were estimated from measurements of body density, as determined by hydrostatic weighing. In addition, participants also collected 5-day diet records (4 weekdays, 1 weekend day) in the 2 weeks before the start of the investigation. These records were analyzed using a computer-based nutrient analysis program (Nutritionist IV, First Data Bank, San Bruno, CA)

### Table 1  Subject Characteristics

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Body fat (%)</th>
<th>( \dot{V}O_{2\text{peak}} ) (ml · kg(^{-1} ) · min(^{-1} ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21</td>
<td>174</td>
<td>60.3</td>
<td>17.2</td>
<td>45.5</td>
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<tr>
<td>2</td>
<td>22</td>
<td>168</td>
<td>77.0</td>
<td>29.3</td>
<td>51.9</td>
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<td>3</td>
<td>22</td>
<td>169</td>
<td>58.7</td>
<td>22.4</td>
<td>44.4</td>
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<td>22</td>
<td>170</td>
<td>70.4</td>
<td>19.2</td>
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<td>5</td>
<td>22</td>
<td>163</td>
<td>56.7</td>
<td>21.5</td>
<td>46.2</td>
</tr>
<tr>
<td>6</td>
<td>21</td>
<td>167</td>
<td>58.8</td>
<td>23.2</td>
<td>48.6</td>
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<td>7</td>
<td>23</td>
<td>172</td>
<td>64.3</td>
<td>22.5</td>
<td>43.9</td>
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<td>23</td>
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<td>63.7</td>
<td>24.7</td>
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<td>21</td>
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</tr>
<tr>
<td>Mean</td>
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<td>61.6</td>
<td>21.9</td>
<td>46.4</td>
</tr>
<tr>
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<td>0.2</td>
<td>1.1</td>
<td>2.4</td>
<td>1.1</td>
<td>1.1</td>
</tr>
</tbody>
</table>
determine the habitual energy and macronutrient intakes of the participants (Table 2). These records were also used to create both 3-day dietary checklists and 3-day prepackaged diets that were isoe nergetic, isonitrogenous, and matched to the individuals habitual macronutrient intakes. Participants abstained from caffeine for at least 12 hours prior to any exercise component of the study and alcohol consumption during the duration of the investigation.

**Study Design and Protocol**

Each participant completed two separate 7-day interventions: a control trial (CON) and a post-exercise supplementation (POST) trial. The energy intake, protein intake, and nutritional composition of the diets during CON and POST were the same as the habitual dietary intake of the participants (Table 2). These trials were separated by at least 1 week, and participants were asked not to discuss with the investigators and other participants which trial they perceived themselves to be on. For 5 of the subjects, the trials occurred on successive weeks and, for the other 5, on successive menstrual cycles. The trials were administered in a randomized, double-blind order, with an independent research technician assigning the trial order and administering the dietary checklists and pre-packaged diets.

A summary of the 7-day protocol is presented in Figure 1A. On day 1–3 of each trial, participants consumed their habitual nutritional intake and followed a dietary checklist. On day 1, subjects arrived in the lab early in the morning prior to consuming their breakfast, and body weight was determined. In the afternoon on day 1, participants performed 1 hour of cycle ergometry at 65% of \( \dot{V}O_2 \) peak. During exercise, participants were allowed to consume water ad libitum, the volume of water consumed was recorded, and the same amount of water was consumed for each of the subsequent rides that were performed (days 3, 4, 6). Following completion of the exercise during POST, the participants consumed a can (250 ml) of a defined formula diet (~66% CHO, 23% PRO, 12% FAT, Results\textsuperscript{TM}, Mead-Johnson, Ottawa, ON) with additional CHO (0.5 g · kg\(^{-1}\) as glucose polymers), while during CON they consumed a can of a placebo beverage (PL; custom made by Mead-Johnson Canada Inc., Ottawa, ON) with added flavoring (Crystal Light\textsuperscript{TM}, Kraft Canada, Don Mills, ON, as a sweetener). The PL beverage was identical to the

<table>
<thead>
<tr>
<th>Diet</th>
<th>Energy intake (kcal)</th>
<th>Protein intake (g · kg(^{-1}) · d(^{-1}))</th>
<th>% CHO</th>
<th>% PRO</th>
<th>% FAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitual</td>
<td>2170 ± 511</td>
<td>1.4 ± 0.2</td>
<td>57.4 ± 6.1</td>
<td>16.7 ± 3.9</td>
<td>25.6 ± 5.5</td>
</tr>
<tr>
<td>CON</td>
<td>2157 ± 476</td>
<td>1.4 ± 0.2</td>
<td>58.0 ± 6.1</td>
<td>16.4 ± 4.0</td>
<td>25.5 ± 5.8</td>
</tr>
<tr>
<td>POST</td>
<td>2157 ± 476</td>
<td>1.4 ± 0.2</td>
<td>58.0 ± 6.1</td>
<td>16.4 ± 4.0</td>
<td>25.5 ± 5.8</td>
</tr>
</tbody>
</table>

*Note.* CON, control condition; POST, post-exercise supplementation condition.
supplement beverage in both visual appearance and taste, but had no energy value. On day 2, no exercise was performed, while on day 3, another 1-hour bout of cycle ergometry at 65% of VO\textsubscript{2peak} was performed in the afternoon. Upon completion of the cycle ergometry on day 3, participants consumed the allocated post-exercise beverage, depending on the experimental condition, and were given their prepackaged diets for the following 3 days (days 4–6).

On day 4 of CON, participants consumed one can (250 ml) of the defined formula diet (66% CHO, 23% PRO, 12% FAT) with additional CHO (0.5 g · kg\textsuperscript{-1} as glucose polymers) with their breakfast, while during the POST condition, they consumed a can of the placebo beverage (PL) (Table 3). Participants then had lunch at approximately 1100 hours, a snack at 1400 hours, then reported to the lab at 1630 hours to perform 60 min of cycle ergometry (60% VO\textsubscript{2peak}). Upon completion of the exercise, the subjects consumed the opposite beverage to that consumed with breakfast (Table 3). Therefore, during the two different trials, nutritional intake was the same; the difference was the time at which the participants consumed the diet (Table 3).

On day 5, participants completed a 24-hour urine collection as previously described (30). In addition, resting expired breath collections were also performed for determination of baseline VO\textsubscript{2}, VCO\textsubscript{2}, and RER. Immediately following baseline collections, participants consumed the PL beverage or the defined formula beverage...
Table 3  Distribution of Nutritional Intake for Each Trial on Days 4 and 6

<table>
<thead>
<tr>
<th>Trial</th>
<th>Breakfast (0800 h)</th>
<th>Lunch (1200 h)</th>
<th>Snack (1500 h)</th>
<th>Post-exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>CON</td>
<td>DFD + B</td>
<td>L</td>
<td>S</td>
<td>PL</td>
</tr>
<tr>
<td>POST</td>
<td>PL + B</td>
<td>L</td>
<td>S</td>
<td>DFD</td>
</tr>
</tbody>
</table>

Note. CON, control condition; POST, post-exercise supplementation condition; DFD, defined formula diet (~66% CHO, 23%PRO, 12%FAT); B, breakfast; L, lunch; S, supper; PL, placebo.

with added CHO, for CON and POST, respectively. Expired resting breath samples were then collected at regular intervals for the next 2 hours to determine the thermic effect of food collected during POST and the resting metabolic rate collected during CON.

On day 6, participants followed the same dietary protocol as that used on day 4. Participants arrived in the laboratory at approximately 1730 hours and a 22-ga catheter was inserted into the median antecubital vein to allow for repeated blood sampling. The catheter was kept patent with 2 ml of an isotonic saline solution following each blood sample. All blood samples were collected into pre-chilled heparinized tubes, centrifuged immediately, and the plasma stored at -50 °C for later analysis. Baseline expired breath samples were then collected prior to 90 min of cycle ergometry at 65% of VO2peak (Figure 1B). Intermittently during the cycling, both expired breath and blood sample were collected (0, 30, 60, and 90 min; Figure 1B). Immediately following completion of the exercise, participants consumed the PL drink or the defined formula drink with added CHO, for CON and POST, respectively. Both intermittent blood samples (120, 150, 180, and 210 min) and breath samples (100, 110, 120, 135, 150, 180, 210 min) were then collected as the subjects rested (Figure 1B). No additional nutritional intake was allowed following consumption of the appropriate beverage following completion of the exercise.

Participants returned the following morning (day 7) to the laboratory in the fasted state. Following body weight determination, the participants performed a ride at 75% of VO2peak until exhaustion (Figure 1A). Subjects were not given any temporal cues, and when the pedal frequency dropped below 50 rpm for 15 s despite verbal encouragement, the test was terminated.

Analysis

Plasma was analyzed for lactate, glucose, sodium (Na\(^+\)), and potassium (K\(^+\)). Plasma lactate was determined using an automated lactate analyzer (YSI-231L, Yellow Springs Instruments, Yellow Springs, OH). Glucose concentrations were determined using a colorimetric based commercially available assay kit (Sigma Diagnostics, Kit#315-100, St. Louis, MO). An automated Na\(^+\)/K\(^+\) automated analyzer was used for determination of plasma Na\(^+\) and K\(^+\) concentrations (KNA2 Analyzer, Radiometer, Copenhagen). HCT was also determined for each blood sample (in
triplicate). Insulin concentrations were determined for baseline, immediately post exercise, and all post exercise time points using standard radioimmunoassay techniques (Diagnostic Products Corporation/Coat-a-Count™, Kit#TKIN5, Los Angeles, CA).

Volumes of 24-hour urine samples were recorded, and several aliquots of each sample were stored at -50 °C for later analysis. Urinary urea nitrogen and creatinine were determined using commercially available colorimetric assay systems (Sigma Diagnostics, Kit#640-A urea nitrogen, Kit#555-A creatinine, St. Louis, MO). The inter-test coefficient of variation for all analysis were less than 10%.

Calculations

Oxygen uptake (\( VO_2 \)) and RER for each time point were calculated as the mean of values across a 5-min sampling period. Resting metabolic rate (RMR) for the two trials was estimated as the \( VO_2 \) at the end of the 120 min of rest on day 5.

Thermic effect of food (TEF) during POST was calculated by subtracting the RMR during CON from the RMR determined during POST on day 5.

Excess Post-Exercise Oxygen Consumption (EPOC) was determined by subtracting the area under the curve of \( VO_2 \) on day 5 from the \( VO_2 \) curve obtained post-exercise on day 6.

Nitrogen balance was estimated for both days 5 and 6 according to the following equation:

\[
N_{bal} = N_{in} - N_{out} \text{ (Urea + Creatinine + Fecal loss + Sweat + Miscellaneous)}
\]

where \( N_{in} \) was determined from dietary analysis, urea and creatinine N losses were determined from biochemical analysis, resting fecal (1.394 g N · d\(^{-1}\)) and sweat losses (0.581 g N · d\(^{-1}\)) were estimated from previous work using a similar subject population (25), and miscellaneous N losses (0.14 g N · d\(^{-1}\); hair, \( N_2 \) gas, toothbrush, toilet paper, etc.) were based on previous reports in the literature (25, 33).

Stoichiometric equations and appropriate energy equivalents (14, 37) were used to calculate carbohydrate (CHO) and fat oxidation rates during steady state, both at rest and during exercise. We assumed that the nitrogen excretion rate was 135 μg · kg\(^{-1}\) · min\(^{-1}\) (27).

Statistics

Data were analyzed using a two-way repeated measures ANOVA for Experimental Condition (CON, POST) and Time. When a significant interaction was found \( p < .05 \), Newman-Keul post hoc technique was used to determine pair-wise differences. Time to exhaustion (day 7) and changes in body mass were compared using a paired t test. All data are expressed as means ± standard error of the mean.

Results

Respiratory Gases

\( VO_2 \) during the 90-min bout of exercise on day 6 was not different between the two conditions. However, there was a trend \( p = .08 \) for \( VO_2 \) to increase during POST
Figure 2 — \( \dot{V}O_2 \) (A) and RER (B) during rest and exercise on day 6. * Significant main effect \( (p < .05) \) for RER, such that CON > POST.

condition as compared to CON late in exercise (Figure 2A). Following the exercise session, a significant main effect was observed for \( \dot{V}O_2 \), such that POST was greater than CON \( (p < .05; \text{Figure } 3\text{A}) \). For \( \dot{V}CO_2 \), no differences were observed between the two conditions during exercise, but during recovery \( \dot{V}CO_2 \) was greater \( (p < .05) \) during CON at 30, 45, 60, and 90 min, as compared to POST. A significant main effect \( (p < .05) \) for RER was also observed during exercise, such that CON was greater than POST (Figure 2B). Significant differences were also observed for RER during recovery. RER was higher at 30, 45, 60, and 90 min during POST as compared to CON (Figure 3B).

**Excess Post-Exercise Oxygen Consumption (EPOC) and Thermic Effect of Food (TEF)**

No significant differences were observed in EPOC for the 120 min following the 90-min bout of exercise on day 6 (CON 18.5 ± 13.3 ml · min\(^{-1}\); POST 3.3 ± 31.0 ml · min\(^{-1}\)). TEF was also calculated for POST on day 6 (POST 20.6 ± 15.3 ml · min\(^{-1}\)).
Substrate Oxidation

Exercise led to increased rates of CHO and fat oxidation (Table 4). Lower rates of fat oxidation ($p < .05$) were observed for CON as compared to POST (Table 4). There was also a trend ($p = .07$) for CHO oxidation to be greater during CON as compared to POST.

Plasma Metabolite and Electrolyte Concentrations

Plasma glucose was not different between the two conditions during exercise; however, by 30 min post-exercise, plasma glucose concentrations were greater ($p < .05$) in POST as compared to CON (Figure 4A). As the post-exercise period continued with POST, plasma glucose concentrations returned to similar levels as those observed with CON.

Plasma lactate concentrations increased ($p < .01$) to a similar extent during the initial 30 min of exercise in the two conditions (Figure 4B). Values then progressively declined both as the exercise continued and into the post-exercise period. No differences in plasma lactate were observed between the two conditions.
Figure 4 — Plasma glucose (A) and lactate (B) concentrations at rest, during exercise, and post-exercise on day 6. *Significantly different from CON \((p < .05)\).

Table 4  Substrate Oxidation During Exercise on Day 6

<table>
<thead>
<tr>
<th>Variable</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>CHO oxidation</td>
<td></td>
</tr>
<tr>
<td>((\mu\text{mol} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}))</td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>18.5 ± 1.4</td>
</tr>
<tr>
<td>POST</td>
<td>16.7 ± 1.8</td>
</tr>
<tr>
<td>Fat oxidation</td>
<td></td>
</tr>
<tr>
<td>((\mu\text{mol} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}))</td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>1.8 ± 0.3</td>
</tr>
<tr>
<td>POST*</td>
<td>2.9 ± 0.4</td>
</tr>
</tbody>
</table>

*Significant main effect \((p < .05)\) for condition, such that POST > CON.
Exercise led to a similar increase \((p < .01)\) in plasma \(\text{Na}^+\) for both experimental conditions (Figure 5A). As the exercise continued, no further alterations in plasma \(\text{Na}^+\) were observed; however, during the post-exercise phase, concentrations were reduced to below baseline values. Plasma \(\text{K}^+\) increased during exercise by 30 min, which was observed during both conditions \((p < .01; \text{Figure 5B})\). No further changes were observed during exercise, but during recovery, there was a more rapid return to baseline levels with POST as compared to CON. Plasma \(\text{K}^+\) concentrations returned to resting levels by 30 min post-exercise during POST, while during CON, values remained elevated (at exercise levels) throughout the recovery period \((p < .05\) between groups).

**Hormones**

Plasma insulin concentration was similar at the onset of exercise on day 6 (Figure 6). Exercise resulted in a decline \((p < .05)\) in plasma insulin for both conditions. However, during recovery, plasma insulin concentrations were greater during POST as compared to CON (Figure 6).
Urine Metabolites

Twenty-four hour urine creatinine excretion was similar for the two conditions on both day 5 and day 6 (Table 5). Similarly, no differences were observed for urinary urea nitrogen (Table 5). However, there was a trend ($p = .07$) for urea excretion to be lower during POST on both day 5 and day 6, as compared to CON.

Nitrogen Balance and Body Mass

During POST, nitrogen balance was positive on both day 5 and day 6, while during CON it was negative (Figure 7). Despite a strong trend ($p = .06$), these differences in nitrogen balance were not statistically different between the two conditions. During CON body mass declined $1.4 \pm 0.4$ kg, whereas with POST body mass declined $0.7 \pm 0.2$ kg. Therefore, POST resulted in a significant ($p < .01$) attenuation in the loss in body mass over the 7-day protocol.
Table 5  Urinary Metabolite Excretion on Days 5 and 6

<table>
<thead>
<tr>
<th>Variable</th>
<th>Day 5</th>
<th>Day 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creatinine (g · 24 h⁻¹)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>1.24 ± 0.14</td>
<td>1.15 ± 0.16</td>
</tr>
<tr>
<td>POST</td>
<td>1.21 ± 0.24</td>
<td>1.12 ± 0.13</td>
</tr>
<tr>
<td>Urea nitrogen(g · 24 h⁻¹)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>10.8 ± 1.1</td>
<td>12.0 ± 0.7</td>
</tr>
<tr>
<td>POST</td>
<td>9.8 ± 1.1</td>
<td>9.8 ± 1.4</td>
</tr>
</tbody>
</table>

Note: CON, control condition; POST, post-exercise supplementation condition.

Time to Exhaustion

POST resulted in a 47% increase \((p < .05)\) in the time to exhaustion on day 7 (CON = 346.0 ± 19.5 s; POST = 509.5 ± 89.3 s).

Discussion

The purpose of the current investigation was to determine the effects of the timing of macronutrient intake on indices of energy balance, protein metabolism, and endurance exercise performance in recreationally trained females exposed to an increase in training volume. The primary finding of the current study was that post-exercise macronutrient intake resulted in an attenuation of the decline in body mass that occurred with an increase in training volume. In addition, the post-exercise macronutrient intake (POST) led to a trend for an improvement in nitrogen balance (more positive) as compared to a post-exercise placebo (CON). Post-exercise macronutrient intake also resulted in an improvement in time to exhaustion during exercise at 75% of \(V_\text{O}_2\text{peak}\) the following morning.

It is well established that endurance and/or resistance exercise results in alterations in protein metabolism. Acute bouts of either endurance exercise or resistance exercise have been observed to alter whole body protein turnover and muscle protein synthesis and degradation \((3, 9, 10, 26)\). Specifically, acute endurance exercise results in an increase in protein oxidation during exercise \((13)\), while a simultaneous increase in muscle protein degradation and muscle protein synthesis are observed in the post-exercise period \((9)\). Acute increases in muscle protein synthesis have also been reported following resistance exercise \((3, 10, 26)\), which can contribute to a more positive net muscle protein balance \((3)\). In addition, it has also been observed that the provision of amino acids \((4)\) or carbohydrate \((30)\) results in a more positive net muscle protein balance following resistance exercise.

Given that the type and amount of nitrogen intake during the two experimental conditions was constant \((25, 33)\), the trends in nitrogen balance observed in the current study were due to alterations in urinary urea nitrogen excretion. A more positive nitrogen balance suggested a net retention of body protein. The trend in the
current study for an increase in urea nitrogen excretion with CON was suggestive of
a reduction in amino acid transamination and oxidative deamination, since urinary
urea excretion is a function of blood urea concentration and glomerular filtration
rate (GFR; 15). Based on the current study design, GFR would have been similar for
the two conditions (identical dietary intake, fluid intake, and exercise). In addition,
no differences in urinary creatinine excretion were observed between CON and
POST. Therefore, the reduction in urinary urea was likely due to a reduction in
protein turnover. Reductions in 24-hour urea nitrogen excretion have been previ-
ously observed with the consumption of carbohydrate (2 g/kg) following acute
resistance exercise (30). Therefore, based on the current findings, it appears that
post-exercise nutritional intake can influence protein metabolism, ultimately lead-
ing to a net retention of body protein.

There are a number of possible mechanisms through which macronutrient
intake could alter protein metabolism. Possible mechanisms include: (a) alter-
ations in branched-chain 2-oxoacid dehydrogenase (BCOAD) activity, (b) alter-
ations in plasma insulin, and (c) provision of exogenous protein/amino acids. The activity of
BCOAD is influenced both by exercise (22,23) and diet (5, 22, 31). More specifically,
acute exercise leads to an increase in the activity of BCOAD (22, 23), whereas the
acute intake of carbohydrate has been observed to result in a decrease in the activity
of the enzyme (22). Such a decrease in activity could contribute to the findings of the
current investigation.

Alterations in plasma insulin could also lead to alterations in protein turnover
following exercise. Infusion mediated increases in circulating insulin concentra-
tions have been observed to attenuate whole body protein oxidation and proteolysis
(34), increase blood flow, stimulate the uptake of amino acids, and increase muscle
protein synthesis (2). It is well established that macronutrient intake following
exercise increases the circulating concentrations of insulin and enhances the rate of
muscle glycogen resynthesis (29, 30, 32, 38). Therefore, the greater circulating
concentrations of insulin observed with POST in the current investigation may have
contributed to the greater net retention of protein and enhancements in performance
observed on day 7.

The provision of amino acids following exercise has also been observed to
improve net protein balance, independent of changes in circulating insulin concen-
trations (35, 36). The combined effects of resistance exercise and amino acid infu-
sion have been observed to result in a more positive net protein balance as compared
to either individually (4). Therefore, the combination of the exercise and the protein
supplied in the beverage during POST may have also contributed to the improve-
ments in protein retention.

The greater reduction in body mass during CON, as compared to POST,
provides further support for the changes observed with protein metabolism. Less of
a decline in body mass occurred as compared to the control condition, despite the
same total daily energy and macronutrient intake, and total volume and intensity of
exercise. This demonstrates the importance of the coordination of both training and
macronutrient intake for athletes. Because we did not measure body composition
before or after each trial, we could not determine definitively whether the losses
were from the fat or fat-free compartments.

Finally, time to exhaustion was greater with POST as compared to CON
during the morning ride on day 7 of the protocol. Since the participants were not
allowed to consume anything following the ride on the evening of day 6, and they arrived in the laboratory in a fasted state on the morning of day 7 to perform the performance trial, it is likely that the increase in performance was due to the greater muscle glycogen resynthesis in the POST condition (29, 30, 32, 38). There has been some suggestion that an adequate total carbohydrate intake over a 24-hour period should be sufficient to maximize muscle glycogen concentration (8). However, the current findings suggest that when repeated bouts of exercise are performed within a single day, post-exercise macronutrient intake may improve exercise performance during subsequent bouts of exercise, despite the consumption of diets of similar total energy and macronutrient proportions. This demonstrates the importance of the timing of nutritional intake following each workout and the implication of this timing on subsequent exercise performance for the following workouts.

In summary, the current study demonstrated that the consumption of macronutrients following exercise can lead to less of a reduction in body mass during a week of increased training volume and a trend for a more positive nitrogen balance. In addition, post-exercise nutritional intake also led to an improvement in exercise performance during a subsequent exercise trial the following morning.

References


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