SHORT-TERM CHANGES IN DIETARY FAT AND CARBOHYDRATES
DO NOT ALTER DUATHLON PERFORMANCE

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Abstract

Purpose: This study investigated the effects of short-term dietary changes on metabolism and duathlon performance. Methods: Eleven males underwent an individual high-fat (HF) (> 65% fat from energy) and a high-carbohydrate (CHO) (HC) diet (> 60% CHO from energy). Energy intake was individualized and commercially available foods were prepared and packaged for each participant 48-h before completing a laboratory-based duathlon (5-km run, 30-km cycling, 10-km run). Blood samples were obtained before, immediately after and 1- and 2-h following the duathlon for determination of glucose, insulin and glucagon. Oxygen consumption (VO2), ratings of perceived exertion (RPE), and respiratory exchange ratio (RER) were assessed and fat and carbohydrate oxidation were estimated before, during, and after the duathlon. Results: Dietary records indicated a significant difference in fat content ingested before the duathlons (p < 0.05). Time to complete the duathlon did not differ between the HC and the HF diet trials. CHO oxidation rate was higher during the HC diet trial than during the HF diet trial (p = 0.006). Fat oxidation rates were higher in the HF diet trial compared to the HC diet trial (p = 0.001). No differences in RPE were found between dietary trials. Blood glucose concentration was higher immediately following duathlon in the HC diet trial than in the HF diet trial, and remained higher 1- and 2-h following duathlon (p < 0.05). Conclusion: Duathlon performance was not altered by short-term changes in dietary fat or CHO composition despite higher blood glucose concentrations under the HC condition. Keywords: dietary manipulation, endurance exercise, metabolism, glycogen loading, fat loading.
Dietary manipulation is a common ergogenic strategy used in an attempt to improve performance. Athletes from different sports have followed short- and long-term dietary regimens where macro and micronutrients, and hydration have widely varied. No single strategy has been shown to be perfect or ideal for a particular sport; however, recent evidence (Erlenbusch, Haub, Munoz, MacConnie, & Stillwell, 2005) supports the contention that most athletes might improve their physiological profile before a race by following some type of moderate to high-carbohydrate (CHO) diet.

Research published as early as 1939 (Christensen & Hansen, 1939) and recent studies (Bergstrom, Hermansen, Hultman, & Saltin, 1967; Erlenbusch et al., 2005; Hawley, Palmer, & Noakes, 1997; Pitsiladis, & Maughan, 1999; Starling, Trappe, Parcell, Kerr, Fink, & Costill, 1997) generally demonstrate a positive physiological profile (e.g., higher muscle glycogen stores, lower RER during exercise) and improved exercise performance (i.e., delayed time to exhaustion) when subjects consumed a short-term diet ($\leq 3$ d) higher in CHO as opposed to a diet high in fat (i.e., low-CHO diet) prior to exercise. These results are more apparent in untrained as opposed to trained subjects, and where positive metabolic and physiological responses observed during exercise do not always extrapolate to improved performance.

Contrary to high-CHO diets, high-fat diets are not usually well accepted and tolerated by athletes during the first days of such a dietary regimen (Helge, Watt, Richter, Rennie, & Kiens, 2001). It has been reported that high-fat diets have negative consequences such as slower gastric emptying, higher ratings of perceived exertion during exercise, higher energy content, and impairments in exercise performance due in part to the inability to sustain high-intensity exercise (Hargreaves, Hawley, & Jeukendrup, 2004; Hawley, Dennis, Lindsey, & Noakes, 1995). Others (Starling et al., 1997; Pitsiladis & Maughan,
1999) have reported high fat oxidation rates during exercise following a low-CHO or a high-fat diet without a concomitant improvement in exercise performance.

Attempting to clarify whether high-fat and high-CHO diets improved performance, a recent meta-analysis (Erlenbusch et al., 2005), showed heterogeneous results, indicating that high-CHO diets do not consistently improve “time to exhaustion-type” of trials compared to high-fat diets. The effect size obtained ($E.S. = -0.60$), a standardized magnitude of the effect of the independent variable on the dependent variable, suggested that in spite of favorable changes in physiological and metabolic profile during exercise, the time to exhaustion was only moderately mediated by a diet high in CHO (Erlenbusch et al., 2005). However, these results are not clearly apparent for combined sports (e.g., duathlon, triathlon and “time trial” studies, where only a few studies were analyzed ($n = 5$) and no $E.S.$ obtained (Erlenbusch et al., 2005).

The growth of endurance enthusiasts and competitions and the ongoing search of diet strategies the days prior to an event are given more attention than in the past. Therefore, the aim of the study was to directly compare the effects of a short-term high-fat (HF) and a high-CHO (HC) diet on metabolism and duathlon performance in trained, competitive young-adult endurance athletes. We hypothesized that performance and metabolic responses in a duathlon were going to be different after two short-term dietary regimens.

**Methods**

**Participants**

Eleven athletes participated in the study. The Institutional Review Board from Auburn University (AU) approved the study, and written informed consent was obtained from each subject.
**Inclusion/exclusion criteria**

Male volunteers were asked to participate if they were between 20 to 44 years of age, had a maximum oxygen consumption (VO$_{2\text{max}}$) $\geq$ 50 ml · kg$^{-1}$ · min$^{-1}$, and were currently trained for competition. Volunteers were not allowed to participate if they reported or exhibited anemia (defined as hemoglobin (Hb) < 8.38 mmol/L and hematocrit (Hct) < 40%), had any gastrointestinal disorders, were under current nonsteroidal anti-inflammatory drugs (NSAID), or had any known food allergies.

**Preliminary assessment**

Volunteers who apparently met the inclusion criteria arrived at the Exercise Technology Laboratory at AU, completed a health history form and underwent a physician screening. Next, participants underwent body composition assessment via dual energy X-ray absorptiometry (DEXA), and a graded maximal exercise test (GXT) on a treadmill to determine maximum oxygen consumption (VO$_{2\text{max}}$) via respiratory gas analysis in a Medgraphics® CPX-Ultima (Minneapolis, MN) metabolic cart.

The oxygen and carbon dioxide sensors were calibrated using gases with known oxygen and carbon dioxide concentrations before each test. The flow sensors were also calibrated before each test using a 3-L syringe. Termination criteria for the VO$_{2\text{max}}$ test were two of the three following criteria: a) a request to stop the test, b) respiratory exchange ratio (RER) $\geq$ 1.15, and/or c) a plateau of the VO$_2$ curve $< 2$ ml · kg$^{-1}$ · min$^{-1}$ with increased workload (Davis, 2005). Candidates who did not achieve at least a VO$_{2\text{max}}$ $\geq$ 50 ml · kg$^{-1}$ · min$^{-1}$ in the treadmill test were excluded from the study.

**Study design**

A crossover design was used where the experimental conditions were randomly assigned to the participants. Thus, in a counterbalanced manner, each athlete performed the
experiment on two different occasions, separated by at least 7 days. The overall protocol is depicted in the diagram 1.

- - - - - - - - Diagram 1 near here - - - - - - - -

*Dietary intervention*

Participants were instructed to record their food consumption over a three-day period (2 weekdays and 1 weekend-day) in a food log to determine food preferences and energy needs. A registered dietitian, using a commercially available software package (NutriCalc Plus, Version 2.1.1, Salem, OR) (ESHA Research, 2005), analyzed all food logs and designed two diets for each participant. Both, the HF and the HC diets met the participant’s daily energy needs as reported in their food logs; however, the objective in nutrient content change was to achieve 65% fat, 20% CHO, and 15% protein for the HF diet, and 60% CHO, 25% fat, and 15% protein for the HC diet. The goal was to match as closely as possible each participant’s energy intake as reported in the food logs.

Diets were prepared by the registered dietitian using commercially-available pre-packaged foods. Foods were prepared for breakfast, lunch, dinner, and snacks. The foods were accompanied by a menu so athletes ate meals according to recommended times and portions sizes. The diet consistent with the experimental protocol was given to each participant 72-h before the experimental duathlon. Participants were instructed to eat the foods according to the allotments for breakfast, lunch, dinner, and snacks 48-h before each experimental exercise session. Actual energy intake was verified by having the participants return empty food wrappers and any unused food to the researchers as they returned to the laboratory.
Experimental exercise session (duathlon)

On the day of the duathlon participants arrived at the laboratory, returned empty food packages and were instructed to void their bladders before body weight was measured. Then, they were instructed to sit quietly for 5-min. Next, a fasting blood sample was obtained. Following the initial blood draw, participants were provided with a standardized breakfast to eat while resting in a comfortable chair for 60-min. The breakfast, identical for both HF and HC conditions, was designed by the registered dietitian and consisted of 51% CHO (48 g), 19% protein (18 g), and 30% fat (13 g) for a total of 1570.1 kJ (375 kcal), and a medium glycemic index of 64.7 (based on 50 g glucose) (Foster-Powell, Holt, & Brand-Miller, 2002).

After the rest period, participants had 10-min to warm up and then started the duathlon by completing a treadmill run of 5-km (Run-1), 30-km stationary cycle (Bike), and 10-km treadmill run (Run-2). The subjects ran at 0% grade and were allowed to modify only the treadmill speed. For the cycling part of the race, participants had previously attached their own bicycles to a CompuTrainer™ (Racer Mate, Inc., Seattle, WA).

The partial, as well as the final time were recorded for further analysis. Athletes were instructed to transition between duathlon segments in the shortest possible time. The transition times between segments of the duathlon were subtracted from the final time. During the duathlon the participants were given the opportunity to drink chilled water *ad libitum*; solid foods were avoided at all times.

Participants were instructed to give their best effort during the duathlon. Volume of carbon dioxide (VCO₂), VO₂, heart rate (beats · min⁻¹), and ratings of perceived exertion (RPE) (Borg, 1998) were monitored during the duathlon to assure an exercise intensity of > 70% VO₂max. These measurements were obtained on all participants at the same time.
periods, every 15 min during each stage of the duathlon. For VO\(_2\) and CO\(_2\) measurements, we had the subjects breathe into the metabolic cart’s collection sample hose for at least 3 min before a reading was obtained. We attempted not to interfere with the participant’s race strategy; therefore, we did not collect data when the subjects were very close to finishing one of the duathlon stages.

Oxidation rates for fat (FOX) and CHO (CHOX) were calculated using the following stoichiometric equations and appropriate energy equivalents assuming a negligible urinary nitrogen excretion as described by others (Achten & Jeukendrup, 2003; Frayn, 1983): FOX (g · min\(^{-1}\)): \(1.67 \times VO_2\) (l · min\(^{-1}\)) – \(1.67 \times VCO_2\) (l · min\(^{-1}\)); and CHOX (g · min\(^{-1}\)): \(4.55 \times VCO_2\) (l · min\(^{-1}\)) – \(3.21 \times VO_2\) (l · min\(^{-1}\)).

Blood samples (described below) were obtained immediately and again 1- and 2-hours after the duathlon. Once the experimental session was completed, the subjects were provided with rehydration fluids, fruits, and an appointment for the next visit to the laboratory. Experimental exercise sessions were separated by at least 7 days.

**Blood sampling and analysis**

Venous blood samples for each participant were collected before, immediately after, 1- and 2-h following the duathlon. Two-7 ml serum BD Vacutainer\(^\circledR\) Blood Collection tubes (Becton, Dickinson, Franklin Lakes, NJ), were obtained at each blood sampling time point. Blood samples were obtained on each participant while seated after a 5-min rest period.

Only blood samples for glucagon analyses were collected in chilled lavender –top tubes containing 100 \(\mu\)L of aprotinin (Sigma, Aprotinin, Cat # A6279). Immediately following the blood draw, a small portion of the sample was collected in three microcapillary tubes and spun in an IEC Micro MB high-speed microcentrifuge.
(International Equipment Company, Needham Heights, MA) to determine hematocrit. To determine Hb concentration another portion of fresh blood (10 µL) was also immediately transferred into a tube containing a previously prepared Hb reagent solution (2.5 mL Sodium Lauryl Sulfate). This mixture was transferred into a cuvette and read at 540 Nm in a spectrophotometer (Spectronic® Genesys™ 2, Spectronic Instruments, Inc., Rochester, NY). The remainder of the blood sample was allowed to clot and serum was separated by centrifugation at 1500 g for 15-min.

Serum aliquots were prepared and stored at –80°C for further analysis of glucose (Glucose Flex® Dimension®, Dade Behring Inc., Deerfield, IL). Enzyme linked-immuno-sorbent assay (ELISA) kits were used for determination of insulin and glucagon (LINCO, St. Charles, MO).

The intra-assay coefficient of variation (CV) for blood glucose was 0.5% and the inter-assay CV was 1.3%. For insulin, the intra-assay CV was 3.3% and the inter-assay CV was 4.7%. All samples from one particular participant were analyzed in the same “run”.

Statistical analysis

Data were analyzed with the Statistical Package for the Social Sciences (SPSS®), version 15.0 for Windows. Data are presented as means (M) and standard deviation (± SD), unless otherwise noted, and statistical significance was set a priori at \( p \leq 0.05 \).

Paired \( t \) tests were used to determine significant mean differences between experimental conditions in the dependent variables performance time in the duathlon (partial and total), diet content composition, and insulin (IN) glucagon (GL) ratio (IN/GL). Factorial 2 (trials) x 4 (pre, immediately post exercise, 1-h, and 2-h post exercise) repeated measures analyses of variance (ANOVA) were computed to analyze glucose. Metabolic (i.e., VO\(_2\), %VO\(_2\), RER, FOX, and CHOX), RPE, and speed variables were analyzed by a 2
(trial) x 3 (run-1, bike, run-2) factorial, repeated-measures ANOVA. For all ANOVA tests, appropriate follow-up analyses were computed if significant interactions and/or main effects were found (e.g., Bonferroni adjustment for multiple comparisons). Finally, Pearson-product moment correlations were obtained to study correlations between performance and biochemical markers.

**Results**

*Participant characteristics*

Eleven healthy young-adult males (aged 36.6 ± 4.9 yrs.) participated in the study. Height, weight, body fat percentage, VO$_2$max, and HRmax were 1.74 ± 0.06 m, 74.47 ± 7.66 kg, 17.22 ± 6.63%, 57.4 ± 7.4 ml · kg$^{-1}$ · min$^{-1}$, and 192 ± 7 beats · min$^{-1}$, respectively. Participants trained for middle and long distance events such as triathlon and marathon completing on average 11 h · wk$^{-1}$, including running on average 13 km · wk$^{-1}$ and cycling 24 to 40 km · wk$^{-1}$. Baseline Hb and Hct values were within normal ranges for adult males (Pagana & Pagana, 2003).

*Diet characteristics*

The final composition of the dietary regime is presented in Table 1. The nutrient composition percentages for both dietary conditions were close to the predetermined goal. In the HF diet, the athletes consumed 2.8, 1.9, and 1.0 g · kg$^{-1}$ · day$^{-1}$ of fat, CHO, and protein, respectively. During the HC diet trial, the CHO, fat, and protein consumed were 6.3, 0.8, and 1.0 g · kg$^{-1}$ · day$^{-1}$, respectively.
Duathlon performance

No differences in performance in the independent segments of the duathlon or in the total duathlon time were observed (Table 2).

 Independently of the dietary trial, the subjects performed the duathlon at 71.07 ± 1.97% of their individually determined VO\textsubscript{2max}; achieving higher %VO\textsubscript{2max} in the run-1 (79.10 ± 2.59%) than in the cycle (64.20 ± 2.19%) and run-2 (69.90 ± 2.49%) (p ≤ 0.001). Also, duathlon’s segment RPEs were higher in the run-2 (16 ± 1) compared to run-1 (14 ± 1) and bike (15 ± 1) (p = 0.030). Heart rate response estimated as a percentage of HR\textsubscript{max} was higher in the run-1 (88 ± 2%) compared to the bike (84 ± 2%) and run-2 (86 ± 2%) (p = 0.011) (Figure 1).

 Regardless of the measurement time, the mean CHO oxidation rate was higher during the HC diet trial than during the HF diet trial (p = 0.006) (Table 3). Also, independently of the diet, CHO oxidation was similar between the run-2 (2.9 ± 0.9 g · min\textsuperscript{-1}) and the cycling segment (2.6 ± 0.8 g · min\textsuperscript{-1}) (p > 0.05), and lower than the run-1 segment (4.2 ± 1.4 g · min\textsuperscript{-1}) (p ≤ 0.01). Regardless of measurement time, FAT oxidation rates were higher in the HF diet trial compared to the HC diet trial (p = 0.001) (Table 3). Independently of the diet, no differences were found in FAT oxidation in the duathlon segments following Bonferroni adjustments for multiple comparisons.
Accordingly, regardless of the duathlon segment, there were lower RER values achieved in the duathlon under the HF diet (0.90 ± 0.01) than under the HC diet (0.96 ± 0.01) \((p = 0.001)\). Also, regardless of the diet, RER values were higher during the run-1 (0.96 ± 0.02) than during the run-2 (0.92 ± 0.01), and cycling (0.91 ± 0.01) segments of the duathlon \((p = 0.005)\).

The fasting IN/GL ratio in the HF diet (0.27 ± 0.10) was lower than the ratio on the HC diet (0.39 ± 0.20) \((p \leq 0.05)\). A combined effect was observed between diet and measurement time in glucose concentrations \((p = 0.004)\). Follow-up analysis indicated lower glucose concentrations in the HF than the HC diet trial immediately, 1-h and 2-h following exercise (Figure 2).

**Discussion**

The aim of the study was to investigate the effects of two short-term dietary changes on metabolism and duathlon performance. We did not find changes in physical performance when young-adult endurance athletes consumed a HF and a HC diet before a duathlon.

In this study, we attempted to alter glycogen stores and therefore initial metabolic state by short-term diet and exercise. These diets have previously shown to reduce liver and muscle glycogen (i.e., energy) stores (Bergstrom et al., 1967; Sherman, Costill, Fink, &
Miller, 1981). In this investigation – although glycogen levels were not directly assessed -, the IN/GL ratio is one biochemical marker that appears to support that in the HF diet the goal was achieved (Brooks Fahey, White, & Baldwin, 2000; Vander, Sherman, & Luciano, 1998). Direct measurement of hepatic glycogen stores is both invasive and expensive. Magnetic resonance imaging is the only way to estimate hepatic glycogen energy in a non-invasive way; however, the costs associated to such a technique are prohibitive. We approached the problem in a different way. We used information provided by glucoregulatory hormones regarding basic information about the initial metabolic state of the liver. A subject in the absorptive state is expected to show a higher [IN] concentration than during post-absorptive state. On the other hand, a subject in the post-absorptive state or fasting is expected to show higher [GL] than [IN] (Vander et al. 1998). Therefore, an elevated IN/GL ratio would indicate an absorptive state and a hypoglycemic state mediated by IN (i.e., high glycogen stores). A reduced IN/GL ratio would indicate a post-absorptive state, meaning a higher glycogenolysis rate and gluconeogenesis in order to maintain normal blood glucose levels (i.e., low glycogen stores) (Brooks et al., 2000). In addition, total liver glycogen content is dramatically reduced following a low carbohydrate diet or 12-h fasting (Houston, 1995). Therefore, by following these regimens, we attempted to change energy stores to study physical performance in a duathlon since a direct correlation is known between muscle glycogen stores and endurance performance (Ahlborg, Bergstrom, Ekelund, & Hultman, 1967; Bergstrom et al., 1967).

The researchers provided two isoenergetic diets to each athlete; however, their nutrient content was different. Previous research on long-duration (2-weeks) dietary modification indicated that HF diets (i.e., defined as having $\geq 30\%$ fat of total energy) significantly reduced pre-exercise glycogen content (Lambert, Speechly, Dennis, &
Noakes, 1994). In the present study, we did not find significant differences in performance times in the duathlon when athletes followed a 2-day HF or HC diet. Previous research on short-duration (4-h) dietary modification reported no significant performance improvements when athletes consumed a HF or a HC diet (Okano, Sato, Takumi, & Sugawara, 1996). Others (Bergstrom et al., 1967; Starling et al., 1997; Pitsiladis & Maughan, 1999; Galbo, Holst, & Christensen, 1979; Martin, Robinson, & Robertshaw, 1978) have also discussed the muscle and liver glycogen depletion and reduction in performance observed when participants followed a 1- to 3-days HF diets.

Recent research showed that a one-day protocol diet providing 10 g CHO · kg⁻¹ of high-glycemic index foods significantly increase muscle glycogen content in males compared to a normal diet providing 5.8 g CHO · kg⁻¹ · day⁻¹ (Bussau, Fairchild, Rao, Steele, & Fournier, 2002). In the present study, the researchers provided ~ 6.3 g CHO · kg⁻¹ · day⁻¹ of mixed glycemic index foods during the HC diet. It remains to be studied what would be the best amount of CHO (i.e., g CHO · kg⁻¹ · day⁻¹) and its glycemic index and glycemic load required not only to increase glycogen stores, but also to improve performance in male athletes. Recent evidence (Chen, Wong, Wong, Lam, Huang, & Siu, 2008), supports the notion that significant changes in metabolic response are observed when consuming different glycemic load regimens before a performance tests is carried out. Chen et al. (2008), designed three isocaloric meals composed of different glycemic index foods with a concomitant different glycemic load. These meals were given to participants 2-h before a time trial test was performed. Chen et al. reported no differences in performance as measured by time to complete a laboratory-based 10-km run.

We found significantly lower RER values in the duathlon when athletes consumed the HF diet compared to when ingested the HC diet, indicating a preferential fat utilization
during exercise and as some have previously suggested, reflective of glycogen sparing (Hargreaves et al., 2004). This finding also agrees with the notion that there is a hierarchy of substrate compensation during exercise in response to a reduced glycogen availability likely to protect against hypoglycemia (Zderic, Schenk, Davidson, Byerley, & Coyle, 2004). Similar findings have been reported in single-sport athletes (e.g., cyclists, runners) consuming HF diets and performing exercise (Coyle, Jeukendrup, Oseto, Hodgkinson, & Zderic, 2001; Fleming et al., 2003; Jeukendrup, 2003; Weltan, Bosch, Dennis, & Noakes, 1998).

In the present study, the CHO oxidation during a combined sport (i.e., duathlon) was higher in the HC condition than in the HF condition, achieving ~3.7 g · min⁻¹.

Hargreaves et al. (2004), indicated that during long duration and high intensity exercise (in single-sports), the rates of CHO oxidation can reach values as high as ~3-4 g · min⁻¹. Nevertheless, the rate of CHO oxidation during prolonged exercise of the present study did not affect performance, since no differences were found between the HF and the HC experimental conditions.

In conclusion, two short-term dietary regimens different in nutrient content did not affect duathlon performance in males differently, despite different metabolic responses. Oxidation of CHO during exercise was higher in the HC diet than in the HF diet, and oxidation of fat during exercise was higher in the HF diet than in the HC diet. Athletes on a HC diet finished the duathlon with higher blood glucose levels than athletes on a HF diet and maintained higher blood glucose levels up to 2-h following exercise. Athletes on a HF diet were hypoglycemic 1-h following exercise. Future research on this topic should determine the effects of short-term dietary manipulations with different amounts of glycemic index foods in combined-sports such as duathlon and triathlon.
References


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Acknowledgments

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Diagram 1. Experimental protocol timeline

- Food pick up - 72 h
- Initiate diet, 60 min run, 70% VO₂max or no exercise - 48 h
- 45 min run, 70% VO₂max or no exercise - 24 h
- Blood sampling -60 min
- Duathlon (running-cycling-running)
- Blood sampling
  - 0-h
  - 1-h
  - 2-h

Post-exercise
Table 1  Diet Composition for the Experimental Conditions (n = 11)

<table>
<thead>
<tr>
<th></th>
<th>High-fat diet</th>
<th>High-CHO diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (kJ)</td>
<td>11,586.7 ± 1,582.9</td>
<td>11,501.3 ± 1,481.0</td>
</tr>
<tr>
<td>CHO (%)(^a)</td>
<td>21.3 ± 1.0</td>
<td>63.5 ± 13.9</td>
</tr>
<tr>
<td>Fat (%)(^b)</td>
<td>67.6 ± 1.1</td>
<td>25.4 ± 14.3</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>11.4 ± 0.7</td>
<td>11.2 ± 0.8</td>
</tr>
</tbody>
</table>

*Note.* Values are $M \pm SD$

\(^a\) $p < 0.001$

\(^b\) $p < 0.001$
Table 2 Overall and Segment Performance Times and Speed in the Duathlon

Under Two Experimental Conditions (n = 11)

<table>
<thead>
<tr>
<th>Performance time (min)</th>
<th>High-fat diet</th>
<th>High-CHO diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall duathlon</td>
<td>136.4 ± 20.1</td>
<td>134.9 ± 20.9</td>
</tr>
<tr>
<td>Run-1</td>
<td>23.5 ± 3.9</td>
<td>23.2 ± 3.8</td>
</tr>
<tr>
<td>Bike</td>
<td>58.9 ± 10.2</td>
<td>59.0 ± 10.4</td>
</tr>
<tr>
<td>Run-2</td>
<td>54.0 ± 10.3</td>
<td>52.7 ± 11.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>High-fat diet</th>
<th>High-CHO diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean speed race</td>
<td>18.6 ± 2.4</td>
<td>18.8 ± 2.5</td>
</tr>
<tr>
<td>Run-1</td>
<td>13.1 ± 2.1</td>
<td>13.2 ± 2.0</td>
</tr>
<tr>
<td>Bike</td>
<td>31.3 ± 4.8</td>
<td>31.3 ± 5.0</td>
</tr>
<tr>
<td>Run-2</td>
<td>11.5 ± 2.2</td>
<td>11.9 ± 2.5</td>
</tr>
</tbody>
</table>

Note. Values are M ± SD
Table 3 Carbohydrate (CHO) and Fat (FAT) Oxidation During the Duathlon Segments ($n = 9$)

<table>
<thead>
<tr>
<th>Substrate oxidation</th>
<th>High-fat diet</th>
<th>High-CHO diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHO oxidation ($g \cdot min^{-1}$)(^a)</td>
<td>2.8 ± 0.9</td>
<td>3.7 ± 1.1</td>
</tr>
<tr>
<td>Run-1</td>
<td>3.7 ± 0.6</td>
<td>4.7 ± 1.4</td>
</tr>
<tr>
<td>Bike</td>
<td>2.3 ± 1.0</td>
<td>2.8 ± 1.4</td>
</tr>
<tr>
<td>Run-2</td>
<td>2.4 ± 0.8</td>
<td>3.4 ± 1.3</td>
</tr>
<tr>
<td>FAT oxidation ($g \cdot min^{-1}$)(^b)</td>
<td>0.5 ± 0.2</td>
<td>0.2 ± 0.2</td>
</tr>
<tr>
<td>Run-1</td>
<td>0.3 ± 0.4</td>
<td>0.0 ± 0.4</td>
</tr>
<tr>
<td>Bike</td>
<td>0.5 ± 0.2</td>
<td>0.3 ± 0.2</td>
</tr>
<tr>
<td>Run-2</td>
<td>0.5 ± 0.2</td>
<td>0.2 ± 0.2</td>
</tr>
</tbody>
</table>

*Note.* Values are $M \pm SD$

\(^a\) $p = 0.006$ between diets

\(^b\) $p = 0.001$ between diets
Figure 1 Ratings of Perceived Exertion (RPE), %HRmax, and %VO2max Responses for 11 Males Completing a Duathlon. Values are M ± SEM
Figure 2 Average Plasma Glucose Concentrations for 11 Males Following a Duathlon Under Two Dietary Conditions. Broken Lines Represent Normal Plasma Glucose Values (3.9-6.1 mmol/L). Values are M ± SEM

* * p < 0.001 between diet conditions