The Effect of Diet Manipulations on Aerobic Performance

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The purpose of this study was to examine the metabolic consequences of a moderate variation in dietary fat content of male endurance athletes during submaximal exercise. Six males (age, 29.8 ± 11 years; weight, 72.3 ± 10 kg) with an average maximum oxygen uptake (VO₂max) of 66 ± 10 ml/kg/min were tested on their normal diet and 3 experimental diets. The energy contributions from protein, carbohydrates, and fats were 16/59/22 (3% alcohol), 14/53/33, 13/72/15, and 16/61/23% for the normal diet (N), fat supplemented diet (F), high carbohydrate diet (C), and adjusted normal diet (AN), respectively. The F diet was designed to significantly increase fat content compared to the normal diet and be easily maintained by the athletes. Caloric content of the F, C, and AN diets were adjusted to meet estimated total daily energy expenditure. The difference between the N and AN diets is that the AN has been adjusted to meet estimated total daily energy expenditure. The diets were randomly assigned after substrate utilization testing on the N diet and were consumed for 7 days prior to testing. Substrate utilization was recorded at steady state (73 ± 1.4% of VO₂max) while running on a treadmill for 40 min. There were no significant differences in respiratory exchange ratio between any of the dietary manipulations. No significant differences were observed for lactate, VO₂, or HR during submaximal testing on the N, F, C, and AN diets. These data indicate that a fat supplemented diet did not affect substrate utilization during 40 min of steady-state submaximal exercise when compared to a high carbohydrate diet or the participant’s normal and adjusted normal diets.

Key Words: RER, fat supplemented diet, high carbohydrate diet, steady-state running, submaximal exercise

Introduction

Many studies have reported enhanced endurance performance following a high carbohydrate diet (3, 5, 9–11, 13, 26, 34, 39, 40), while others have demonstrated the
importance of glycogen stores in endurance events (7, 39). The amount of glycogen stored in the muscle and liver is related to an individual’s capacity for endurance performance (1). Furthermore, the depletion of muscle glycogen stores is known to contribute to fatigue (35). A common adaptation to endurance training is an increased ability to utilize fat as a substrate. The resultant preservation of glycogen stores can ultimately enhance endurance performance (16, 23, 25).

Dietary manipulations to enhance endurance performance have been widely studied. Several studies in humans (28, 29, 31) have assessed the effect of an increase in dietary fat on endurance performance. These studies reported an increased time to exhaustion and improved endurance performance while consuming a high fat diet. Muoio and colleagues (29) manipulated the diet in humans to increase plasma free fatty acid levels and reported increased endurance performance and fat substrate utilization. However, these investigators did not randomize the order of administration of the diets and did not test participants following a normal diet that was adjusted to match the participants’ total daily caloric expenditure. A recent study by Lambert et al. (28) did not report whether the diets met the athletes’ measured or estimated caloric expenditures and did not report results when participants were consuming their normal diet. Furthermore, in this study the high fat diet was 68% fat (by energy), which may be difficult for athletes to consume in a typical diet.

There is considerable evidence that supports a diet high in carbohydrates for optimal training and performance (27, 30, 34, 35, 40). Conversely, there is also evidence to support the hypothesis that due to training adaptations favoring utilization of fats, a diet higher in fat may be advantageous (28, 29, 36). However, most of the studies (1, 22, 24, 28, 29, 31, 32, 36) that have investigated submaximal exercise capacity and substrate oxidation while consuming a high fat diet had participants consume diets with as high as 76% kcal from fat. These severe increases in fat may not be attainable outside of a laboratory setting, and the extreme reduction in carbohydrate yields muscle glycogen levels that are significantly lower than high carbohydrate diets (28). There is little evidence available concerning the effects of a moderate variation of fat within a range that might be reasonably consumed by an endurance athlete and would not severely compromise muscle glycogen stores, but would still increase free fatty acid level to enhance endurance performance. In addition, studies (28, 31) comparing high fat to high carbohydrate diets measured endurance performance as time to exhaustion on a specific diet at low intensity (less than 60% \( \dot{V}O_{2\text{max}} \)). However, the goal of endurance athletes is to enhance performance for a specific distance (i.e., 10k race, marathon, etc). If endurance performance could be enhanced by dietary manipulation of fats and carbohydrates, the goal of the diet would be to utilize more fats and conserve glycogen stores during high intensity thus allowing the athlete to improve his or her performance.

Therefore, the purpose of the present study was to examine the metabolic consequences of variations in dietary fat and carbohydrate contents that are within a range that can be reasonably expected to be consumed by endurance athletes on substrate utilization during 40 min of steady state exercise at 75% of \( \dot{V}O_{2\text{max}} \). We hypothesized that respiratory exchange ratio (RER) during submaximal exercise would be lower while consuming a fat supplemented diet due to the increased fat availability caused by the increase in fat consumption in the diet.
Methods

Participants

Six male endurance runners volunteered as participants. The criteria to qualify as endurance trained was a maximum oxygen consumption ($V\cdot O_2^{max}$) $> 50$ ml/kg/min on a progressive treadmill test and a minimum training regimen of 3 days a week for 30 min for the past 3 months. All participants participated in an orientation session during which they were familiarized with testing procedures, the recording procedures for the 3-day diet record, and the importance of accuracy in recording the food intake. The study had previously been approved by the Institutional Review Board of James Madison University, and participants provided their informed written consent prior to participation.

Design

Participants performed an initial evaluation to determine body composition, dietary intake, caloric expenditure, and $V\cdot O_2^{max}$. Participants returned to the laboratory after a minimum of 3 days from the initial evaluation to perform the substrate utilization test on their normal (N) diet. Participants were required to refrain from engaging in strenuous physical activity for 24 hours prior to all substrate utilization tests. After completing the N diet substrate utilization test, participants were randomly assigned to one of three experimental diets for 7 days. All three of the experimental diets were adjusted to meet the participant’s estimated daily caloric expenditure. The experimental diets were a fat supplemented diet (F), high carbohydrate diet (C), and the participant’s normal diet adjusted to meet their estimated total caloric expenditure (AN). On the morning of the 8th day of each of the experimental diets, the participant completed the substrate utilization test and were randomly assigned a new diet for another week. This procedure continued until participants had completed each experimental diet.

Initial Evaluation

The participant’s 3-day food records were reviewed with the investigator to assure proper procedures were followed during recording. Participants completed a Seven-Day Physical Activity Recall Questionnaire that was used to estimate daily caloric expenditure (33). Body composition was determined using the Jackson and Pollock 7-site skinfold technique (20). $V\cdot O_2^{max}$ was determined using a progressive continuous treadmill test. The speed of the treadmill was set at a comfortable running speed for the participant. Every 3 min, the grade was increased 3% until voluntary exhaustion. This portion of the test was followed by a 6-min low-intensity active recovery. Following the recovery period, the speed was increased to the original running speed, and the grade was increased to 3% greater than the participant had reached before. The participant ran until voluntary exhaustion, again to verify $V\cdot O_2^{max}$ (37). Criteria for $V\cdot O_2^{max}$ were respiratory exchange ratio (RER) $> 1.1$ and a plateau of $V\cdot O_2$, which all participants met. Oxygen consumption was measured using a computerized metabolic cart (MMC Horizon, SenorMedics, Yorba Linda, CA, USA). Heart rate was recorded every minute using a heart rate monitor (Polar CIC, Inc., Port Washington, NY, USA) and rating of perceived exertion was recorded at the end of each stage.
Substrate Utilization Test Protocol

Participants reported to the laboratory in the morning following a 12-hour overnight fast. Participants were weighed and a blood sample was drawn to determine resting blood lactate and glucose levels. Prior to the substrate utilization test, a 5- to 10-min warm-up and stretching period were performed before each test. The substrate utilization test consisted of 40 min of running on a level treadmill at 70–75% \( \dot{V}O_{2\text{max}} \). The 40 min were divided into four 10-min segments. At the end of each segment, the participants stopped running briefly so that a blood sample could be obtained. Blood samples were taken using the finger stick method (12) and analyzed for blood lactate and blood glucose levels using an automated lactate analyzer (YSI 2300 STAT Glucose/Lactate analyzer, Yellow Spring Instrument Company, Inc., Yellow Spring, OH, USA). The glucose/lactate analyzer was calibrated prior to each test and standards prepared by the manufacturer were measured to verify linearity. Heart rates were recorded every minute of exercise using a heart rate monitor (Polar CIC, Inc., Port Washington, NY, USA). Oxygen consumption, respiratory exchange ratio, and ventilation were measured using a computerized metabolic cart (MMC Horizon, SenorMedics, Yorba Linda, CA, USA) during the last 2 min of each of the four 10-min segments. The mouthpiece and noise clip were in place for at least 1 min before the final 2 min of each stage. The substrate utilization test was performed after each of the diets.

Dietary Protocol

After completion of the orientation, participants completed a food preference questionnaire. The food preference questionnaire consisted of food items generated from the database of Auto Nutritionist IV (First Data Bank, N2, San Bruno, CA, USA) in which the participants checked off items they preferred to eat. These items were later used to create each participant’s diet. In addition, the participants completed a 3-day food record. Participants were asked to record all foods and beverages consumed for a Thursday, Saturday, and Monday. This method has been shown to have a 0.95 correlation to a 7-day food record (4). All diets were analyzed using the Nutritionist IV (v. 7.0, N2 Computing, Salem, OR, USA) to determine macronutrient and caloric intake. A 7-day activity questionnaire was used to estimate each participant’s daily caloric expenditure (32). If the participant’s diet met estimated daily caloric expenditure, no change was made to his or her normal diet for the adjusted normal (AN) diet. If the diet was deficient in calories, food portions were adjusted using Auto Nutritionist IV (First Data Bank, N2, San Bruno, CA, USA) to meet total estimated caloric expenditure. This was done without changing the distribution of fats, carbohydrates, or proteins.

The fat supplemented diet was designed to consist of similar energy composition from protein as the normal diet (16%), 50% kcal from carbohydrates, and 34% kcal from fats. (Participants’ actual diets consumed differed; see Table 2.) This diet was designed to significantly increase fat content compared to the N and C diets and be easily prepared and consumed by the athletes. The carbohydrate diet (C) was designed to consist of same kcal from protein as the normal diet (16%), 73% kcal from carbohydrate, and 11% kcal from fats. (Participants’ actual diets consumed differed; see Table 2.) All diets were designed using the participant’s food preference questionnaire and Auto Nutritionist IV. A complete 7-day diet consisting of
breakfast, lunch, dinner, snacks, and quantities of each item was given to each participant at the beginning of the week. Participants measured and weighed food and fluid intake then checked off each item they consumed. If additional items were consumed or changes in amounts prescribed occurred, participants added quantities and items to their diet record. The carbohydrate diet was supplemented with high carbohydrate energy bars (Gatorbar) and drinks (Gatorload). Diets were analyzed at the end of each week to determine total calories consumed and the percentages of fats, carbohydrates, and proteins by calories.

**Statistical Procedures**

The exercise data were analyzed using a mixed model repeated measures factorial ANOVA (SAS v. 8.1). The 4 experimental diets (N, AN, C, and F) and 4 submaximal exercise time periods (10, 20, 30, and 40 min) formed the factorial. The dependent variables for each time period were \( \overline{V} \cdot O_2 \), RER, blood lactate, HR, and RPE, resulting in 4 repeated measures for each participant. To fit the correlation structure between repeated measures within subject, several different variance–covariance structures were examined. The best fitting variance–covariance structure based on the Bayesian Information Criterion was selected. The degrees of freedom method used was Kenward-Roger.

For all analyses, the residuals for the dependent variable met the assumptions of variance homogeneity and normality for the analysis of variance. Values are presented as means ± SD. Tests of hypotheses with probabilities < .05 were considered statistically significant.

**Results**

The physical characteristics of the 6 participants are shown in Table 1. The participants exercised at an intensity equal to 73 ± 1% of their \( \overline{V}O_{2\text{max}} \) during the 40-min substrate utilization test for all diets. There were no significant differences in \( \overline{V}O_2 \) during the 40-min exercise period among the diets (Table 3).

**Table 1  Physical Characteristics of Subjects (n = 6)**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>29.8 ± 11</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>178.6 ± 6</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>72.3 ± 10</td>
</tr>
<tr>
<td>% body fat</td>
<td>9.1 ± 5.0</td>
</tr>
<tr>
<td>( \overline{V}O_{2\text{max}} ) (ml/kg/min)</td>
<td>66.7 ± 10</td>
</tr>
<tr>
<td>Caloric intake (kcal/d)</td>
<td>3403 ± 782</td>
</tr>
<tr>
<td>Caloric expenditure (kcal/d)</td>
<td>3800 ± 690</td>
</tr>
<tr>
<td>Training (days/week)</td>
<td>4.5 ± 1</td>
</tr>
<tr>
<td>Training (min/day)</td>
<td>54 ± 13</td>
</tr>
</tbody>
</table>
The compositions of the N, AN, C, and F diets are reported in Table 2. The N diet was found to be, on average, 397 ± 417 kcal/d deficient. For the individuals who were deficient, adjustments in their total caloric intake were made by increasing caloric intake without changing their dietary composition. The contribution of fat and carbohydrates of the F diet were significantly different from the N and C diets. The C diet also differed significantly in fat and carbohydrate content from the N diet. Bodyweight did not change significantly during any of the 7-day periods on the different diets.

Diet had no effect on RER during the 40 min steady-state exercise bout (Table 3). RER for all diets for the entire 40 min averaged 0.94 ± 0.01. Heart rate throughout

Table 2 Composition of the Normal (N), Adjusted Normal (AN), and Carbohydrate (C) and Fat Supplemented (F) Diets

<table>
<thead>
<tr>
<th>Diet</th>
<th>Kcal/d</th>
<th>Protein %</th>
<th>CHO %</th>
<th>Fat %</th>
<th>Alcohol %</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>3403 ± 782</td>
<td>16 ± 1.8</td>
<td>59 ± 9.7</td>
<td>22 ± 9.7</td>
<td>3 ± 2.4</td>
</tr>
<tr>
<td>AN</td>
<td>3800 ± 690</td>
<td>16 ± 1.6</td>
<td>61 ± 8.0</td>
<td>23 ± 7.9</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>3800 ± 690</td>
<td>13 ± 1.4</td>
<td>72 ± 5.1*</td>
<td>15 ± 4.8*</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>3800 ± 690</td>
<td>14 ± 1.7</td>
<td>53 ± 3.7†</td>
<td>33 ± 3.0†</td>
<td></td>
</tr>
</tbody>
</table>

Note. All values presented as the mean ± SD. *Differences significant at the .05 level compared to the normal diet. †Differences significant at the .05 level compared to the normal and carbohydrate diet.

Table 3 Respiratory Exchange Ratio (RER), Oxygen Consumption (\(\dot{V}_O_2\)), and Heart Rate (HR) Recorded During the Substrate Utilization Test

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Normal diet</th>
<th>Adjusted normal diet</th>
<th>Carbohydrate-supplemented diet</th>
<th>Fat-supplemented diet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RER  (\dot{V}_O_2) HR</td>
<td>RER  (\dot{V}_O_2) HR</td>
<td>RER  (\dot{V}_O_2) HR</td>
<td>RER  (\dot{V}_O_2) HR</td>
</tr>
<tr>
<td>10</td>
<td>0.95 50.1 160</td>
<td>0.95 47.4 154</td>
<td>0.95 48.7 153</td>
<td>0.95 48.6 154</td>
</tr>
<tr>
<td>20</td>
<td>0.94 49.8 163</td>
<td>0.94 47.8 156</td>
<td>0.95 49.0 156</td>
<td>0.94 48.0 157</td>
</tr>
<tr>
<td>30</td>
<td>0.94 49.8 166</td>
<td>0.95 48.1 159</td>
<td>0.94 49.0 159</td>
<td>0.94 48.0 160</td>
</tr>
<tr>
<td>40</td>
<td>0.94 49.6 167</td>
<td>0.94 47.5 161</td>
<td>0.93 48.9 160</td>
<td>0.94 47.9 160</td>
</tr>
</tbody>
</table>

Note. All values presented as means; \(n = 6\). HR in beats per minute, \(\dot{V}_O_2\) in ml/kg/min. No significant differences were evident among the diets for RER, \(\dot{V}_O_2\), or HR, during any of the time periods.
the 40 min for the N diet was slightly higher than that of the other three diets (Table 3), but the differences were not significant. Blood lactate levels were not significantly different between any of the diets at any time point.

**Discussion**

This study sought to determine if substrate utilization during steady-state exercise was affected by dietary manipulation. The participants performed the exercise test following 7 days of a normal, adjusted normal, high carbohydrate, and fat supplemented diets. The results indicate that dietary manipulations of fat, carbohydrates, and calories had no effect on substrate utilization during 40 min of exercise at 73% of VO$_{2\text{max}}$. Furthermore, there were no significant differences in VO$_2$, HR, or blood lactate during the substrate utilization test while consuming any of the diets.

The average VO$_{2\text{max}}$ (66.7 ± 10 ml/kg/min) of these runners would classify them as highly trained. It has been previously reported that highly trained runners have a higher lipid utilization and higher stored glycogen levels than untrained (18, 19). It is also known that endurance training results in decreased utilization of muscle glycogen and increased utilization of muscle triglycerides (16, 19, 21, 23). An increase in utilization of muscle triglycerides may help conserve glycogen stores and allow enhanced endurance performance.

The relationship between fat utilization and performance has caused researchers to examine the impact of increasing the availability of free fatty acids (FFA) for oxidation by increasing the dietary intake of fats relative to carbohydrates. Dietary manipulation may result in an increase in circulating FFA, which would potentiate the oxidation of fat, thus conserving glycogen and improving endurance performance. The results of this study indicated that during a steady-state exercise bout at 73% of VO$_{2\text{max}}$, diet did not have an effect on the respiratory exchange ratio. Thus, in the present study, increasing the amount of fat consumed in the fat supplemented diet by a moderate amount (11% and 18% greater than the normal and high carbohydrate diets, respectively) did not decrease the reliance on carbohydrates as an energy source during steady-state submaximal exercise.

Muoio et al. (29) reported a significant increase in VO$_{2\text{max}}$ and endurance performance while consuming a diet high in fat (38%) for 7 days compared to a high carbohydrate diet. However, in that study, the participants’ diets were not randomized, and there was not an experimental diet that consisted of the participant’s normal diet adjusted to meet their daily caloric expenditure. These methodological weaknesses, which the present study corrected for, may have contributed to the increased endurance performance while consuming the high fat diet. In addition, Muoio et al. (29) reported that plasma FFA levels were higher in the fat diet compared to the carbohydrate diet, which additionally may have contributed a sparing of muscle glycogen and enhancing endurance performance. However, this is only speculation since muscle biopsies were not performed. Others (6, 38) have found that elevated FFA levels reduce the breakdown of glycogen during exercise; therefore, based on these studies, we hypothesized that the supplemented fat diet would reduce substrate utilization.

The present study did not support a diet supplemented with a moderate amount of fat as a means for enhancing substrate utilization especially if an athlete was looking to enhance his performance in a race via a short term (7 days or less) dietary manipulation. With the exception of Muoio et al.’s study, others (1, 14, 24) conclude
that short term increases (less than 7 days) in dietary fat impair endurance performance in untrained individuals. In this study the intensity of the exercise was 73% of \( V\text{O}_{2\text{max}} \); however, during a race athletes may be competing at even higher intensities thus increasing the demand on glycogen stores. Although in this study, and that of Muoio et al. (1994), muscle biopsies were not taken, other studies (1, 39) have shown that a diet higher in carbohydrates increases muscle glycogen stores, therefore increasing the ability of the muscle to perform work at a higher intensity for a longer period of time. A recent study (15) that compared muscle glycogen levels before and after 4 weeks of a high fat or a high carbohydrate diet found that the high carbohydrate individuals had muscle glycogen levels 40% greater in the vastus lateralis than the high fat participants. In addition, both groups significantly increased their endurance performance after 4 weeks of training and consuming the experimental diets; however, there was no difference between the two groups in time to exhaustion. Participants in some of the studies that have shown increases in endurance performance after consuming a diet high in fats exercised for a long duration and/or at a low intensity (24, 28, 29, 31). Performances of longer duration and lower intensity should precipitate an increase in fat oxidation irrespective of previously consumed amounts of fat, carbohydrates, and proteins (2, 8).

In the present study, the fat comprised 33 ± 3% of the fat supplemented diet in terms of kcals, which is lower than diets previously used by other investigators (24, 28, 29, 31). However, the variations in fat content between the experimental diets in this study were significantly different from one another. In addition, the participants in this study indicated that they found it difficult to increase their fat intake from the normal range of 22% to 33% fat. Therefore, expecting an athlete to increase dietary intake to 70% fat before a race to increase endurance performance may not be practical.

The results of this study indicated that for this group of male runners, the diets tested did not significantly affect substrate utilization during steady-state treadmill running. Therefore, for endurance athletes seeking to enhance their performance in a race in which their intensity is going to be greater that 73% of their \( V\text{O}_{2\text{max}} \), it would be advantageous for them to consume a diet high in carbohydrates for peak performance, as previous research has indicated.

**References**


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