The Effect of Preexercise Carbohydrate Status on Resistance Exercise Performance

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The purpose of this study was to determine the effect of a high vs. a low preexercise carbohydrate (CHO) diet on performance during multiple sets of resistance exercise. Eleven resistance-trained males performed cycle ergometry to deplete quadriceps muscle glycogen stores, followed by 48 hr of a high (HICHO) or a low (LOCHO) CHO diet. Subjects then performed five sets each of squats, leg presses, and knee extensions (resistance = 15 RM) to failure. Blood samples were taken before and during exercise for determination of glucose and lactate (LA). No differences in performance (repetitions × weight lifted) were observed (HICHO = 15,975 ± 1,381 and LOCHO = 15,723 ± 1,231 kg). Blood glucose was significantly higher after exercise for HICHO compared to LOCHO (HICHO = 4.8 ± 0.2 vs. LOCHO = 3.9 ± 0.2 mmol-L⁻¹). No differences in LA accumulation were observed. The data indicated that preexercise CHO status did not affect resistance exercise performance. Further, the differences in blood glucose and the similarity in LA responses suggest that glycolysis was maintained in the LOCHO condition, and there may have been an increased reliance on blood glucose when preexercise CHO status was low.

Key Words: anaerobic exercise, blood glucose, blood lactate, weight lifting

It has been recognized for a number of years that endurance exercise performance is influenced by carbohydrate (CHO) status prior to and during exercise (1, 9). Muscle and liver glycogen depletion has been associated with decrements in performance; conversely, elevations in preexercise glycogen levels induced by dietary/exercise regimens have been shown to enhance endurance performance (9). As a result, endurance athletes typically attempt to maximize CHO intake in order to maintain a high CHO status.

Intake of CHO by bodybuilders and those engaging in resistance exercise training tends to be lower than that found in endurance athletes, since a greater emphasis is placed on protein intake for bodybuilders and weight lifters (24). Indeed, it has been observed that a high-CHO diet (65% of total calories) does not
facilitate strength or lean body mass gains compared to a moderate CHO diet (40% of total calories) (17). Nevertheless, it is clear that intense resistance exercise can place a significant demand on muscle glycogen (18, 21). While CHO status may have little impact on an actual competitive performance, it may affect the quality of a training session of resistance exercise, thus affecting training responses (12, 23).

Although the relationship between CHO status and endurance exercise performance has been established, the effect of CHO status on high-intensity, short-duration exercise (i.e., sprint and resistance exercise) has not been studied extensively (23). Studies designed to investigate the effect of preexercise glycogen levels on performance in anaerobically based exercise have produced mixed results. Previous investigators have reported that a high relative to a low CHO status (brought about by diet/exercise regimens) improves (4, 8, 14, 15) or does not affect (6, 20, 22, 25) high-intensity, short-duration exercise performance. Studies dealing specifically with metabolism and performance during resistance exercise are limited, but a significant reliance on muscle glycogen during resistance exercise has been reported (18, 21). Lambert et al. (12) provided data indicating that performance might be enhanced when subjects were fed a glucose polymer before and during multiple sets of resistance exercise; however, their study did not involve the manipulation of preexercise CHO status.

Because of the lack of information regarding the relationship between CHO status and resistance exercise performance, the purpose of this study was to determine the effects of low- and high-CHO diets on resistance exercise performance. Specifically, we studied the effect of a depleting bout of exercise followed by 48 hr of either a high (7.66 g CHO · kg body mass−1) or a low (0.37 g CHO · kg body mass−1) CHO diet on the performance of multiple sets of squats, leg presses, and knee extensions. Associated metabolic responses such as blood glucose and blood lactate were also examined. It was hypothesized that resistance exercise performance would be impaired due to the CHO restriction, and that significant alterations in blood lactate and glucose responses would occur.

**Methods**

**Subjects**

Subjects were 11 recreational weight lifters whose primary mode of training was resistance exercise and who had engaged in a regular regimen of resistance training of at least four sessions per week for the previous 2 years. Subjects were screened for participation using a comprehensive medical questionnaire, and they signed an institutionally approved informed consent form. Subject characteristics were as follows: age = 23.6 ± 1.1 years, weight = 84.0 ± 2.3 kg, height = 178.4 ± 2.5 cm, \( \dot{V}O_{2\max} = 3.51 ± 0.17 \) L · min−1, and 15 repetition maximums (15 RM) = 99.8 ± 4.2, 122.3 ± 14.0, and 39.2 ± 5.2 kg for the squat, leg press, and knee extension, respectively.

**Experimental Design and Testing**

Each subject participated in a high-CHO (HICHO) and a low-CHO (LOCHO) condition in a counterbalanced crossover design, with each condition separated by at least 2 weeks. Subjects were initially tested for maximal aerobic capacity (\( \dot{V}O_{2\max} \)) using a graded protocol on a Monark cycle ergometer. This test consisted
of 3-min stages with 40-W increases in resistance until standard termination criteria were met (RER > 1.10, age-predicted heart rate, a lack of elevation in $V_O_2$ with increasing resistance, inability to maintain the required cadence, and voluntary termination). Throughout the test, expired air was collected using a one-way mouthpiece, and gas analysis was performed on a Vista metabolic cart (Vacumed, Ventura, CA). The $V_O_2$ max test was used to determine exercise intensity on depletion rides. On a separate day, additional preliminary testing was conducted, which consisted of determining each subject's 15 RM for the squat, leg press, and knee extension exercises. The procedure to determine the 15 RM began with a weight estimated by the subject based on his training experience. Depending on the number of repetitions completed at the starting weight and the subject's assessment of the difficulty of the set, the weight was systematically increased or decreased. The performance segment of the experimental testing protocol was also simulated. The squats were performed using free weights, the leg press was performed on an inclined sled, and the knee extension was performed on a Nautilus® machine.

The experimental trial began with a ride on a cycle ergometer designed to deplete the quadriceps muscle group of glycogen. This consisted of 60 min of riding at 70% of $V_O_2$ max followed by six 1-min sprints at 115% of $V_O_2$ max, with 1 min rest between each sprint. This protocol has been shown to deplete the vastus lateralis of glycogen (3). For the next 48 hr, no activity was allowed and subjects consumed either a high-CHO diet (7.66 g CHO · kg body mass$^{-1}$) or a low-CHO diet (0.37 g CHO · kg body mass$^{-1}$), the energy content of which was based on the individual caloric intake during the 3-day pre-experimental period. In the HICHO condition, the subjects were given dietary guidelines to follow to produce the desired CHO intake. The recommended food items were fruit, fruit juice, bagels, bread, cola, and pasta with tomato sauce. In the LOCHO condition, they were given the actual food to consume, which consisted of cheese, eggs, bacon, tuna, and hamburger. In both conditions, subjects were given 1 L of a colored, flavored, textured, noncaloric solution to consume during the 48-hr period of dietary control. They were told that the solutions were two different experimental drinks that were being studied. This was done in an attempt to minimize performance effects that might occur as a result of being unable to keep subjects blind to the treatment. Subjects were instructed on how to record their intakes (quantities and food descriptions), and dietary records were kept for the 3 days prior to each experimental trial and for the 48-hr period from the depletion ride to the performance test. These records were analyzed by computer (Nutri-calc Plus) for caloric and macronutrient content.

After the 48 hr of dietary control, the subjects returned to the laboratory and rested in a seated position for 15 min, after which a blood sample was taken from an antecubital vein (the “pre” sample). Prior to the performance test, subjects were allowed a standardized warm-up (duplicated for LOCHO and HICHO) consisting of a short set (8–12 reps) of light squats (2 subjects completed ≤5 min of cycle ergometry prior to the squat warm-up). The performance test consisted of five sets beginning at the 15 RM for each of the three lifts, with each set continuing to failure; thus, the number of repetitions varied from 15 depending on the subject's performance for each set. The squats and leg presses were completed with a cadence that produced an approximate time of 3 s per repetition and the knee extensions with a cadence that produced an approximate time of 2 s per repetition; all lifts were done with an emphasis on the eccentric phase. The full range of motion was required for each repetition.
A rest period of 3 min was allowed between each set and between exercises. For a given set, as fatigue occurred, if between 10 and 12 repetitions were completed, the weight for the next set was reduced by 9.0 kg for the squat and leg press and by 4.5 kg for the knee extension exercises. If 9 or fewer repetitions were completed, the weight was reduced by 18.0 kg for the squat and leg press and 9.0 kg for the knee extension. This scheme was adopted in an attempt to keep the point of failure as close to 15 repetitions as possible and the corresponding time required for each set between 30 and 40 s. Performance was quantified as the total weight lifted, a value derived simply by multiplying the total number of repetitions for a set by the weight lifted per repetition. The values from the sets within a lift were totaled to obtain a performance measure per lift, and values from all sets across lifts were totaled for an overall performance measure.

Additional blood samples were taken immediately after the last set of leg presses (the “mid” sample) and again after the last set of knee extensions (the “post” sample). A 0.5-ml aliquot of whole blood was immediately removed from the sample and combined with 1.0 ml of 8% perchloric acid. This mixture was mixed and centrifuged and the supernatant stored at –80 °C for subsequent analysis of lactate using an enzymatic spectrophotometric method (13). The remaining blood was allowed to clot and was then centrifuged. The serum was removed and also stored at –80 °C for subsequent analysis of glucose using a colorimetric enzymatic method (Sigma procedure #520, St. Louis, MO).

**Statistical Analysis**

All data were analyzed using a one- or a two-factor analysis of variance (ANOVA) for repeated measures. In the two-factor analyses, the first factor was Condition (HICHO and LOCHO) and the second factor was Time (which had three levels: pre, mid, and post for the blood variables) or Lift (which also had three levels: squat, leg press, and knee extension for performance). Performance was analyzed both by Condition and Time using the two-factor analysis and by Condition only with all three lifts combined using the one-factor analysis. Significant ANOVAs were clarified using a Newman Keuls post hoc test. Pearson correlations were run between the dependent variables: blood glucose, blood lactate, and performance. All data are expressed as the mean ± SE. Significance was accepted at the p < .05 level.

**Results**

The subjects’ dietary intakes during the 3 days before and the 48-hr period within each experimental trial are displayed in Table 1. There were no significant differences between conditions for total calories, CHO, fat, and protein consumed during the 3-day preexperimental period. The experimental diets did not differ in caloric intake; however, intakes of CHO, fat, and protein were different as dictated by the experimental design. The mean body weights before the depletion ride and before the experimental trial were 84.04 ± 2.29 and 83.83 ± 2.28 kg, respectively, for the HICHO condition and 83.81 ± 2.37 and 83.27 ± 2.37 kg, respectively, for the LOCHO condition. There were no differences between conditions for either predepletion or preexperimental body weights.

There were no significant differences in performance between the HICHO and LOCHO conditions with either a Condition by Lift analysis (Figure 1) or with
a Condition analysis when all three lifts were combined. The average number of repetitions per set, the kilograms per repetition, and the time per set for all three lifts are shown in Table 2, and the set-by-set resistance and repetition responses are shown in Figure 2. There were no differences between conditions for these variables when analyzed by lift or by individual set. The total numbers of sets requiring load adjustments were not different between conditions and were as follows: 16, 32, and 9 for HICHO, and 18, 33, and 9 for LOCHO for the squat, leg press, and knee extension, respectively. These were out of a total of 55 sets per lift (11 subjects × 5 sets).

Table 1  Dietary Records Before and During the Experimental Period

<table>
<thead>
<tr>
<th>Variable</th>
<th>Condition</th>
<th>Energy (kcal)</th>
<th>CHO (g)</th>
<th>CHO (g·kg body mass⁻¹)</th>
<th>Fat (g)</th>
<th>Protein (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-Day preexperimental diet</td>
<td>HICHO</td>
<td>2,794.6</td>
<td>352.8</td>
<td>4.23</td>
<td>102.2</td>
<td>116.0</td>
</tr>
<tr>
<td></td>
<td>SE</td>
<td>224.7</td>
<td>26.1</td>
<td>0.34</td>
<td>13.7</td>
<td>11.2</td>
</tr>
<tr>
<td>Experimental diet</td>
<td>LOCHO</td>
<td>2,891.2</td>
<td>373.4</td>
<td>4.50</td>
<td>98.0</td>
<td>128.8</td>
</tr>
<tr>
<td></td>
<td>SE</td>
<td>361.8</td>
<td>45.4</td>
<td>0.58</td>
<td>14.4</td>
<td>28.2</td>
</tr>
<tr>
<td>Experimental diet</td>
<td>HICHO</td>
<td>3,206.3</td>
<td>642.6</td>
<td>7.66*</td>
<td>33.0*</td>
<td>84.8*</td>
</tr>
<tr>
<td></td>
<td>SE</td>
<td>88.2</td>
<td>21.1</td>
<td>0.19</td>
<td>2.9</td>
<td>5.0</td>
</tr>
<tr>
<td>Experimental diet</td>
<td>LOCHO</td>
<td>3,093.6</td>
<td>31.6</td>
<td>0.37</td>
<td>229.7</td>
<td>225.6</td>
</tr>
<tr>
<td></td>
<td>SE</td>
<td>63.5</td>
<td>1.6</td>
<td>0.02</td>
<td>5.2</td>
<td>4.6</td>
</tr>
</tbody>
</table>

*Note. All values are daily intakes. *Different from LOCHO, p < .05.

Figure 1 — Performance. The performance measurement (kg) was derived by multiplying the number of repetitions for each set by the weight lifted each repetition. The total for all five sets of the squats, leg presses, and knee extensions is represented.
Table 2  Repetitions Per Set, Kilograms Per Repetition, and Set Duration

<table>
<thead>
<tr>
<th>Variable</th>
<th>Condition</th>
<th>Squat</th>
<th>Leg press</th>
<th>Knee extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repetitions-set⁻¹</td>
<td>HICHO</td>
<td>14.4</td>
<td>12.2</td>
<td>14.2</td>
</tr>
<tr>
<td></td>
<td>SE</td>
<td>0.5</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>LOCHO</td>
<td>14.1</td>
<td>12.3</td>
<td>14.2</td>
</tr>
<tr>
<td></td>
<td>SE</td>
<td>0.4</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>kg-repetition⁻¹</td>
<td>HICHO</td>
<td>96.5</td>
<td>109.8</td>
<td>37.1</td>
</tr>
<tr>
<td></td>
<td>SE</td>
<td>4.6</td>
<td>13.1</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>LOCHO</td>
<td>95.7</td>
<td>108.2</td>
<td>36.1</td>
</tr>
<tr>
<td></td>
<td>SE</td>
<td>4.2</td>
<td>12.5</td>
<td>4.4</td>
</tr>
<tr>
<td>Set duration (s)</td>
<td>HICHO</td>
<td>42.4</td>
<td>38.5</td>
<td>30.1</td>
</tr>
<tr>
<td></td>
<td>SE</td>
<td>2.5</td>
<td>3.2</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>LOCHO</td>
<td>39.6</td>
<td>37.9</td>
<td>29.8</td>
</tr>
<tr>
<td></td>
<td>SE</td>
<td>2.6</td>
<td>3.0</td>
<td>1.7</td>
</tr>
</tbody>
</table>

There were no differences between conditions in blood lactate; however, there was a significant main effect for time, which showed that both the mid- and postexercise levels were greater than the preexercise level in both conditions (Figure 3). There was a significant interaction in the blood glucose responses, which revealed that the mid- and postexercise responses were significantly lower in the LOCHO compared to the HICHO condition (Figure 4). No significant correlations were observed.

Discussion

The primary finding in this investigation was that CHO status did not influence resistance exercise performance as assessed using the model developed for this study. The similarity in performance occurred despite differences in preexercise CHO intake, which we assume lowered muscle glycogen, and despite differences in postexercise blood glucose between the HICHO and LOCHO conditions. Although glycogen determinations were not made, Symons and Jacobs (20) used a similar protocol and reported significant preexercise differences in glycogen (427 vs. 153 mmol · kg dw⁻¹). Their depletion exercise was more severe than ours; however, previous work has shown that the exercise protocol employed in this study produces low glycogen levels in the vastus lateralis (3). Furthermore, the separation in dietary intake in the study by Symons and Jacobs (20) was less extreme (approximately 1.0 g · kg body mass⁻¹ for low CHO, and a self-selected mixed diet for normal CHO) compared to that used in the present study (0.37 g · kg body mass⁻¹ in LOCHO and 7.66 g · kg body mass⁻¹ in HICHO). It is likely, therefore, that there was a difference between preexercise CHO status in the LOCHO and HICHO conditions.

Performance Results

To our knowledge, few if any investigations have been conducted to determine the effect of CHO status on multiple-set resistance exercise performance (23, 24).
Investigators have, however, studied the influence of CHO intake on other forms of short-duration, high-intensity exercise using a variety of models and addressing a number of issues related to metabolic responses and performance outcomes. Performance results from these studies have been equivocal (5, 6, 8, 14, 15, 20, 22, 25).

The studies by Maughan and Poole (14), Pizza et al. (15), and Young and Davies (25) using cycle ergometry, running, and electrically evoked contractions, respectively, have produced the most dramatic results regarding the influence of CHO status on short-duration, high-intensity performance. These investigators showed that supramaximal exercise performance was impaired following a low-CHO diet and enhanced following a high-CHO diet compared to normal intake. Other investigators showed that a low-CHO diet impaired performance but a high-CHO diet did not improve performance above that observed with a normal diet (5, 8). These results suggest that in short-duration, high-intensity activity, performance may be affected by high and low CHO intake, such as that employed in the present
Figure 3 — Blood lactate responses. △ indicates that the mid and post time points are different from the pre time point in both the LOCHO and HICHO conditions. Pre, mid, and post correspond to before exercise, after the leg press, and after the knee extensions, respectively.

Figure 4 — Blood glucose responses. *Significant difference between conditions. △ indicates that post is different from pre in HICHO only. Pre, mid, and post correspond to before exercise, after the leg press, and after the knee extensions, respectively.
study. On the other hand, others showed that muscular strength and endurance and time to exhaustion were not affected by preexercise glycogen levels (6, 20, 22).

The results of these investigations are difficult to compare to each other and to the present investigation due to differences in the methods used to manipulate preexercise glycogen levels and the evaluation of performance. Regardless of these differences, however, the issue is whether the rate of anaerobic glycolytic energy production is decreased when muscle glycogen levels are low, thus impairing performance. It was hypothesized that glycolytic flux would be decreased in the LOCHO condition due to the reduced CHO status; however, the similarity in performance and lactate levels in the LOCHO and HICHO conditions suggests that this was not the case.

Studies designed to evaluate the relationship between glycogen levels and glycogen metabolism have produced conflicting results. Previous work has suggested that the rate of glycogenolysis is influenced by the level of glycogen stores (4, 11, 16); however, more recent findings suggest that the rate of glycogen breakdown is independent of preexercise glycogen levels (19, 22). Regardless of the answer to this controversy, the amount of glycogenolysis during multiple sets of resistance exercise has been shown to be substantial and is proportional to intensity; thus, it may be assumed that in the present study, the demand for glycogen as an anaerobic substrate was relatively large (18, 21). Using the rates of glycogenolysis reported by Robergs et al. (18) for six sets of six repetitions of knee extensions at 70% of 1RM (0.46 mmol · kg ww⁻¹ · s⁻¹), the total demand for glycogen in the present study would be unrealistically high (approximately 250 mmol · kg ww⁻¹ based on 9 min of exercise at 0.46 mmol · kg ww⁻¹ · s⁻¹). The rates reported by Tesch et al. (21), on the other hand, for five sets each of six to eight repetitions of front squats, back squats, knee extensions, and leg presses (0.07 mmol · kg ww⁻¹ · s⁻¹) would give a total glycogen use of approximately 38 mmol · kg ww⁻¹, a reasonable value. With this value, or even one slightly greater, if decreased muscle glycogen does not impair the rate of glycogenolysis, the absolute amount of glycogen may have been high enough to maintain performance in the LOCHO condition. An important issue is that our performance model involved adjustments in resistance across sets; thus, the absolute intensity of the exercise was not constant. While this method may have influenced the rate of glycogenolysis within a trial, the model was based on the premise that if glycogen availability was an influential factor, fewer adjustments would be necessary in the HICHO condition. Fewer adjustments, therefore, would result in a greater absolute amount of weight lifted. In addition, the contribution of the adenosine triphosphate–phosphocreatine system during the 30- to 40-s bouts, particularly with a 3-min rest period for phosphagen resynthesis, must not be overlooked when examining the performance results.

**Blood Lactate**

There are limits in using lactate accumulation as an indicator of anaerobic glycolytic energy production; however, the current blood lactate results may provide insight into the relationship between CHO status and short-duration, high-intensity energy production. A number of investigators have reported that alterations in preexercise glycogen levels do not influence blood and/or muscle lactate levels (19, 20, 22), while others have found a relationship between lactate and preexercise muscle glycogen (4–6, 11, 14). A more detailed analysis by Jacobs (7) led to the conclusion
that there may be a critical level of glycogen (proposed to be 40 mmol·kg ww⁻¹) below which lactate levels are reduced.

The presence or absence of a relationship between lactate and glycogen levels has been found both with (5, 14, 15) and without (19–22) performance differences; thus, the lack of agreement cannot be attributed to differences in total work performed or the duration of exercise. This leads to the conclusion that there is not a tight relationship between preexercise muscle glycogen, lactate accumulation, and high-intensity exercise performance. The similarity in performance and blood lactate results in the LOCHO and HICHO conditions of the present investigation supports this conclusion.

**Blood Glucose**

An additional question that arises is whether, in the presence of reduced muscle glycogen, blood-borne CHO can be taken up at a rate sufficient to fuel anaerobic glycolysis during high-intensity activity. Because rates of appearance and disappearance are not known, interpretation of the blood glucose responses in the present study is difficult; however, the differences between conditions may provide some insight into the role of extramuscular CHO as a source for glycolysis. During the initial segment of the performance trial, blood glucose became elevated in the HICHO condition, which was probably due to sympathetically mediated release of glucose from hepatic stores. The maintenance of blood glucose suggests that during this segment in the LOCHO condition, either no uptake occurred, or, despite the reduced CHO status, some hepatic release occurred, at least at a rate equal to uptake. This would be possible if the exercise/dietary regimen did not completely deplete hepatic stores and/or if some resynthesis took place during the 48-hr dietary control period. The decline occurring at the end in the LOCHO condition, in the face of continued elevation in the HICHO condition, suggests that uptake was occurring at a rate greater than release, a response that may have indicated decreased hepatic release and/or increased uptake. The fact that blood glucose did not reach hypoglycemic levels indicates that even if the muscles were relying heavily on this source of CHO, there was still adequate substrate available to fuel glycolysis.

The work of Lambert et al. (12), where CHO feedings before and during multiple sets of resistance exercise tended to improve performance, suggests that an extramuscular source of CHO may play a significant role in fueling glycolysis. Conversely, the finding of Katz et al. (10), that the contribution of blood glucose to anaerobic glycolysis during high-intensity activity is minimal, casts some doubt on the preceding conclusions.

**Conclusion**

During multiple sets of resistance exercise, the manipulation of dietary intake of CHO over a 48-hr period following depleting exercise did not influence performance assessed using the variable-intensity model developed for this study. The lack of difference between the HICHO and LOCHO conditions may be attributed to the fact that, even though muscle glycogen levels were low, there was adequate CHO to fuel the activity and the rate of glycolysis was not impaired by the low levels. It is also possible that some CHO was derived from blood glucose uptake. From a practical standpoint, the significance of performance assessment during
multiple-set resistance exercise lies primarily in the effect on the quality of a training session where a large volume of work is performed.

References


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