ABSTRACT

PETTEYS, C. L. The effect of pre exercise feeding on endurance performance. MS in Adult Fitness/Cardiac Rehabilitation, December 2002, 27pp. (C. Foster)

Glycogen depletion can have a deleterious effect on endurance performance. The use of carbohydrates ingested either before exercise or during has been a topic of numerous studies. However previous studies have been seriously limited by the use of non-athletically representative outcome measures. This study was designed to test whether or not ingesting a carbohydrate solution 30 min prior to endurance exercise would have an effect on endurance performance. Ten well-trained cyclists performed three 40 km time trials (one for habituation purposes), using a control and a carbohydrate solution (35 grams). Time to completion, power output, velocity, blood lactate, blood glucose (BG), HR, and RPE were measured during the ride. There were no significant differences, except for a significant drop in BG at the beginning of the ride. Based on these results, the use of carbohydrates before endurance exercise does not hinder endurance performance.

THE EFFECT OF PRE EXERCISE FEEDING ON ENDURANCE PERFORMANCE

A MANUSCRIPT STYLE THESIS PRESENTED

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THE GRADUATE FACULTY

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CARRIE LYNN PETTEYS

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THESIS FINAL ORAL DEFENSE FORM

Candidate Carrie Lynn Petteys

We recommend acceptance of this thesis in partial fulfillment of this candidate's requirements for the degree:

Master of Science in Adult Fitness/Cardiac Rehabilitation

The candidate has successfully completed the thesis final oral defense.

	ESS	6/18/02
Signature of Thesis Chairperson	Department	Date
	ESS	6/18/02
Signature of Committee Member	Department	Date
Glenn Brice	Biology	6/18/02
Signature of Committee Member	Department	Date

This thesis is approved by the College of Health, Physical Education, Recreation, and Teacher Education.

	10-1-02
Associate Dean, College of HPERTE	Date
	10-1-02
Director of University Graduate Studies	Date

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INTRODUCTION

There is a rich literature demonstrating that endurance performance is directly related to muscle glycogen concentration. When muscle glycogen becomes depleted, either through heavy exercise or low dietary carbohydrate (CHO) intake, endurance performance suffers (5). It is known that ingestion of CHO during exercise sufficient to maintain blood glucose can partially offset the effects of muscle glycogen depletion (2,3). On the other hand, pre-exercise ingestion of CHO, which can be a strategy for "topping off" muscle and liver glycogen stores, can cause a transient rise in insulin levels (3). This insulinemia, in turn, can block free fatty acid (FFA) release. With depressed FFA release, lipid oxidation is restricted as a source of energy for working muscles, increasing the reliance on glucose and glycogen for energy sources. This is thought to decrease the time to muscle glycogen depletion (3,4), and hasten the onset of fatigue. Experimental evidence supporting this view was provided by Foster et al. (4) who demonstrated reduced endurance time during high intensity (~80% $V0_2$ max) cycling when exercise began 30 minutes following consumption of 75 grams of CHO. Other studies (9) have shown that pre-exercise carbohydrate feedings can have a beneficial effect on endurance performance, if ingested more than one hour before exercise, which presumably allows for augmentation of muscle and liver glycogen stores and a return toward normal of circulating insulin levels before the beginning of exercise.

Previous studies of the effect of pre-exercise feedings have been limited by the use of endurance time as an outcome measure (4,9). Studies in South Africa (6,7) have demonstrated that time trials are much more realistic and reliable than endurance time. Additionally, prior studies of pre-exercise feedings utilized fairly limited warm-up procedures, certainly less than the often intense and extensive warm-up employed by athletes prior to competition. Accordingly, the purpose of this study was to reevaluate the findings of earlier studies (4,9) on the impact of pre-exercise CHO feedings on endurance performance, with the inclusion of a more real world exercise task and with warm-up procedures that closely mimic the pre-competitive behavior of athletes. On the basis of the mixed results from previous studies we have formulated the null hypothesis: pre-exercise feedings will have no effect on endurance performance.

The results of this study could have a direct impact on the regimen of diet and exercise for athletes training for endurance events. With this information, athletes participating in an endurance type activity may come to a better understanding of how carbohydrates, used at the appropriate time prior to exercise, may provide maximum benefit for increasing performance.

METHODS

Ten well-trained cyclists participated in this study. Descriptive characteristics for the subjects are provided in Table 1. The protocol was approved by the Institutional Review Board for the Protection of Human Subjects of the University of Wisconsin-La Crosse. Each subject provided informed consent (Appendix A) and underwent preliminary measurements of age (years), height (cm), weight (kg), ventilatory thresholds, and maximal oxygen uptake (VO_2 max) prior to testing. VO_2 max and ventilatory thresholds were measured during incremental cycle ergometry using open circuit spirometry according to well-accepted diagnostic criteria (8).

<u>Testing Protocol</u>

Prior to the experimental protocol, each subject completed a practice 40-kilometer (km) time trial in order to become habituated to the task. The subjects were instructed to participate in a light workout the day before testing and to maintain a high carbohydrate diet throughout the length of the study. The subjects were required to arrive at the laboratory 30 minutes prior to testing and to be at least three hours post prandial. Each subject performed two experimental 40 km time trials on a wind-braked cycle ergometer. Subjects were instructed to finish the ride as quickly as possible, as if in a race situation. They were provided with continuous visual feedback regarding velocity and distance throughout the ride. Prior to each experimental time trial the subjects performed a standard warm-up of approximately 15 minutes duration, including 2-3 minutes at a very high intensity (> VT2). During the 30-minute interval between the warm-up and the beginning of the 40 km time trial the subjects consumed, in random order, 35 grams of carbohydrate diluted in 600 ml, or 600 ml of water. Subjects were allowed 4-7 days between trials.

During each trial, blood glucose and lactate were measured in blood samples taken from the fingertip. An initial measurement was made at rest, and subsequent measurements were taken at 2.5 km, 5 km, 10 km, 15 km, 20 km, 30 km, and 40 km. Lactate samples were analyzed using an enzyme electrode system (YSI Model 1500 Sport Lactate Analyzer). Glucose samples were analyzed using dry chemistry (Precision QID Glucose Monitor). Heart rate was measured using radio telemetry. Velocity ($m \cdot s^{-1}$), distance (km), time, and power output (Watts) were measured using a strain gauge based dynometer built into the chain ring (SRM, Juelich, Germany), with results averaged over each 2.5 km segment of the ride. Ratings of perceived exertion were documented at the above distances using the category ratio scale. The subjects had a single bottle of water (400 ml) which they consumed ad libidum during the trial.

Statistical Analysis

Repeated measures ANOVA was used to test the hypothesis that pre-exercise feeding of CHO would not have a significant ($p < 0.05$) effect on 40 km time trial performance. When justified by ANOVA, post hoc analyses were made using the Tukey test.

Table 1. Mean (± sd) Descriptive Characteristics of Subjects

Variables	Males (n = 9)	Females (n = 1)
Height (cm)	177 ± 5	182
Weight (kg)	79.5 ± 12.3	79.6
Age (yrs)	37.4 ± 10.6	23
Max Power Output (Watts)	346 ± 54	275
VO_2 Peak ($L*min^{-1}$)	4.14 ± 0.62	2.64
VO_2 at VT 1	2.34 ± 1.33	1.95
VO_2 at VT 2	2.81 ± 0.50	2.10
HR Peak (bpm)	169 ± 14	153
HR at VT 1	146 ± 12	143
HR at VT 2	160 ± 16	144

RESULTS

The mean (± sd) time required to complete the control (C) and carbohydrate (CHO) trials was 75.43 ± 6.32 and 74.12 ± 5.09 minutes, respectively (Figure 1). These times were not significantly different, although it is fair to note that 8 out of 10 subjects were faster during the CHO trial and that a 1:20 difference in performance (1.8%) would be highly meaningful competitively. Most of the time difference was accrued during the final 10 km of the time trial.

The serial values for power output during the C and CHO trials are presented in Figure 2. No significant effects were found for the drink or the drink by distance interaction. For both trials, power output stayed relatively constant over the first 30 km, and then increased during the last 10 km. The average power output during the time trials (~ 195 Watts) was ~58% of the maximal power output observed during incremental exercise testing. On the basis of conventional conversions from power output to VO_2 (1), this power output would represent a VO_2 of ~2.68 $L \cdot min^{-1}$ or ~67% of VO_2 max.

The serial values for velocity during the C and CHO trials are presented in Figure 3. Velocity showed no significant effects for the drink or the drink by distance interaction. As with power output, velocity was relatively constant during the first 30 km and then increased during the last 10 km of the ride.

The serial values for blood lactate are presented in Figure 4. There were no significant effects found for the drink or the drink by distance interaction. Blood lactate levels remained relatively constant (~ 3-4 $mmol \cdot L^{-1}$) for the first 30 km and then increased significantly during the last 10 km of the ride.

The serial values for blood glucose are presented in Figure 5. There was a significant decrease in blood glucose during the first 5 km of the CHO trial. After this, however, there were no differences throughout either ride.

The serial values for heart rate are presented in Figure 6. No significant effects were found for the drink or the drink by distance interaction. The mean heart rate at 10 km (~ 140 bpm) and 40 km (~ 158 bpm) represented 83% and 94% of the maximal heart rate, respectively, observed during preliminary incremental testing.

The serial values for RPE are presented in Figure 7. There were no significant effects for the drink or the drink by distance interaction. RPE was approximately 8 at the end of each ride (> very hard). Some of the subjects rated the ride 10 (i.e. maximal competitive effort).

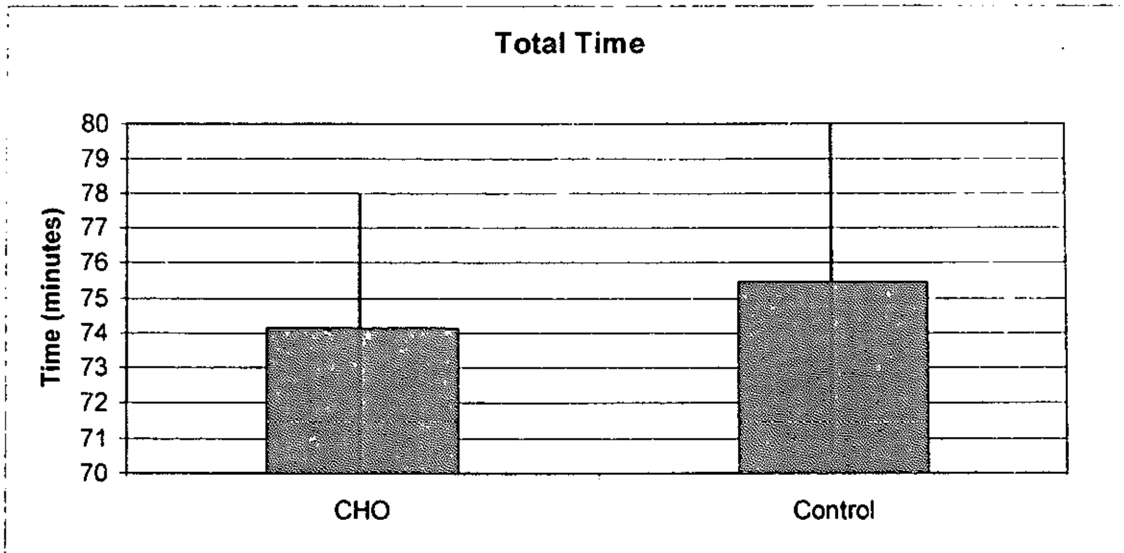

Figure 1. Total time for Carbohydrate and Control trials (mean ± sd).

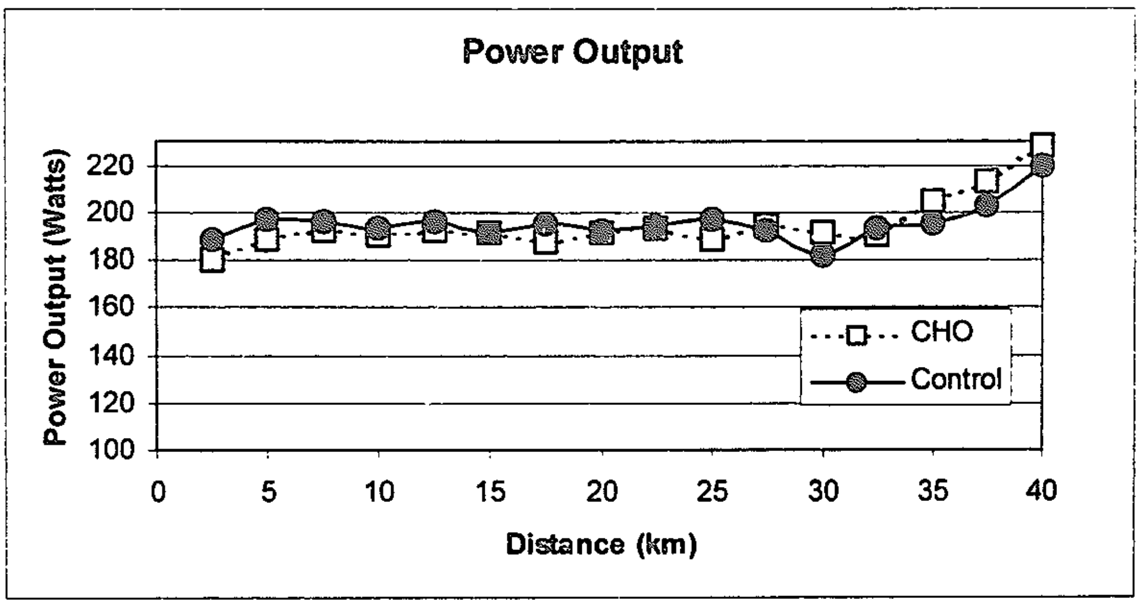

Figure 2. Mean power output for Carbohydrate and Control trials.

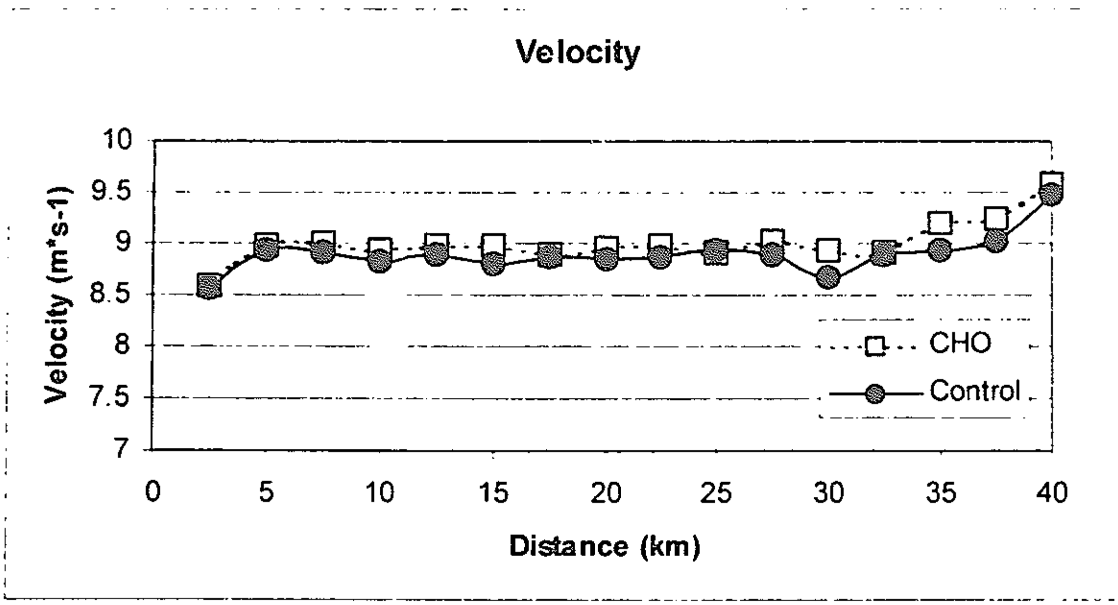

Figure 3. Mean velocity during Carbohydrate and Control trials.

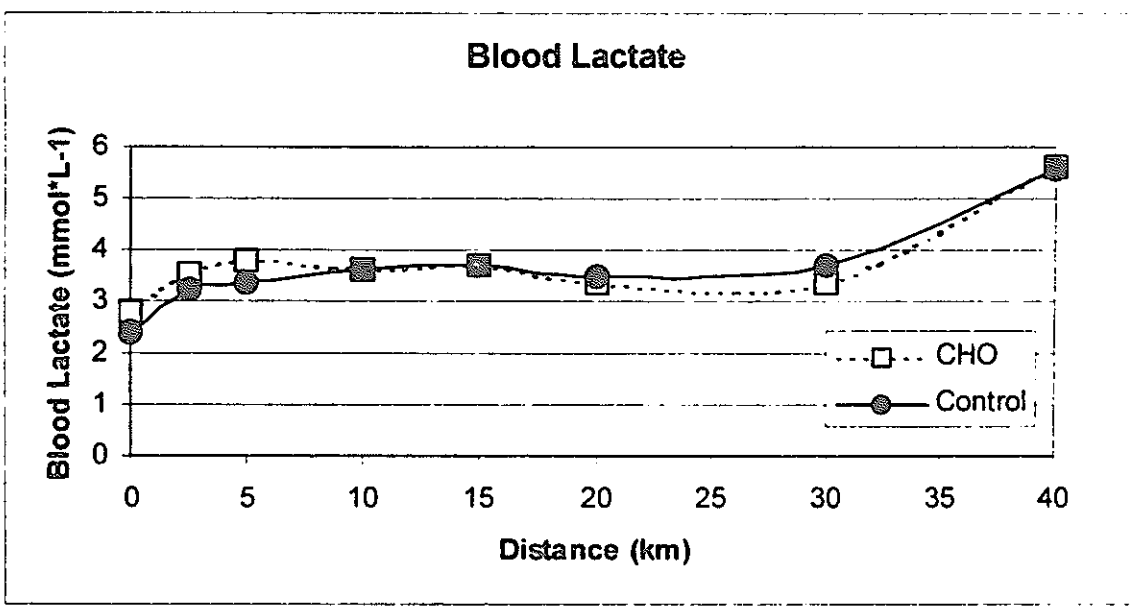

Figure 4. Mean blood lactate during Carbohydrate and Control trials.

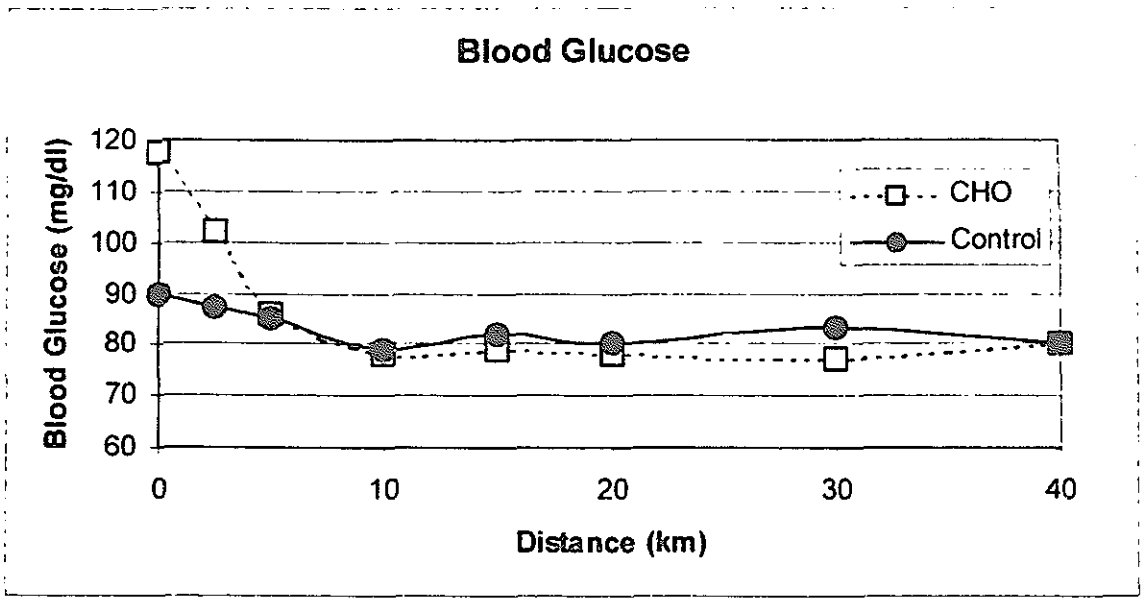

Figure 5. Mean blood glucose during Carbohydrate and Control trials.

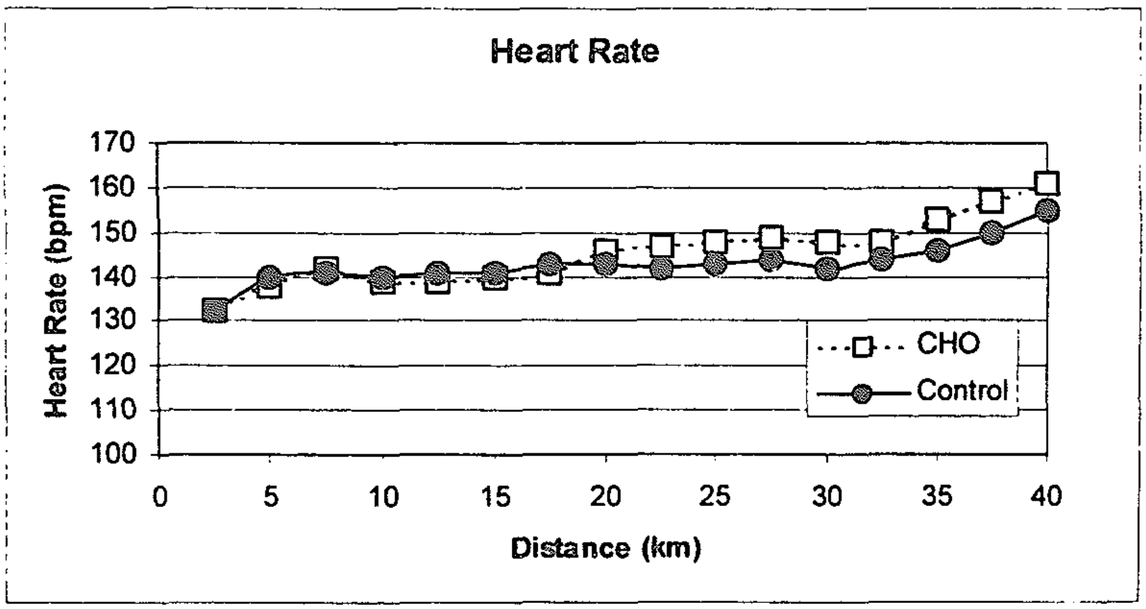

Figure 6. Mean heart rate during Carbohydrate and Control trials.

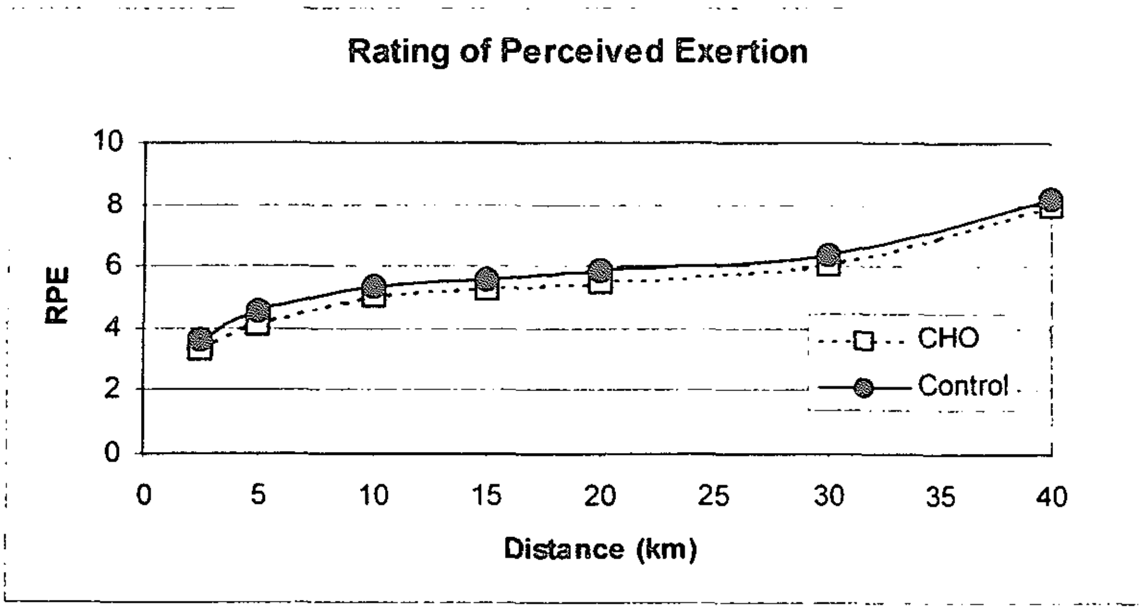

Figure 7. Mean RPE during Carbohydrate and Control trials.

DISCUSSION

The present study found that pre-exercise feeding of CHO had no significant effect on performance time in 40 km cycling time trials. Mean time to completion was not statistically significantly different, even though the CHO trial was completed 1:20 faster and 8 of 10 subjects were faster during the CHO trial. This difference would be highly meaningful for athletes in a competitive situation. Power output, velocity, blood lactate, blood glucose, heart rate, and RPE were similar for both the control and CHO trials. It is interesting to note that power output and velocity appeared to increase earlier over the last 10 km of the ride in the CHO trial. This may also prove beneficial for athletes, providing a late race "kick." These findings supported our hypothesis that pre exercise feeding of CHO would not have a significant effect on 40 km time trial performance.

An earlier study done by Palmer et al. (5) found that CHO feeding 15 minutes prior to exercise had no effect on performance. Their subjects ingested an 8ml/kg body mass solution that was either a placebo or contained 6.8 g/100ml of CHO and then performed a 20 km time trial as quickly as possible. The results showed similar values for mean completion time and power output for both the placebo and CHO trials. Our findings would agree with this study in the fact that we showed no difference in completion time or power output between placebo and CHO trials. In our study, subjects ingested 35 grams of CHO, which was similar to the Palmer et al. study (~39 grams of CHO). A 40 km time trial was performed in our study, as opposed to the 20 km time trial used in the earlier study.

Foster et al. (3) found that pre-exercise feeding of CHO decreased time to exhaustion (i.e. hindered performance) during cycling endurance performance. Instead of using time trials, they used time to exhaustion as a performance marker. However, subsequent studies have shown time to exhaustion to be a relatively poor marker of endurance performance (6). It was shown that ingestion of 75 grams of CHO 30 minutes prior to exercise had an unfavorable effect on endurance performance. The significant drop in blood glucose because of the hyperinsulinemia following the feeding was thought to have impaired lipid oxidation as an energy source. This potentially increased CHO utilization, hastening time to fatigue. Although it was shown that blood glucose levels returned to near normal levels after 30-40 minutes of exercise, it may be assumed that the transient hypoglycemia served to limit CHO oxidation from glucose and increased reliance on muscle glycogen. Subjects in the current study also showed a significant drop in blood glucose levels over the first 5 km of the CHO ride, leveling off at normal values for the duration of the trial. As opposed to the previous study, the current study did not find that CHO feeding 30 minutes prior to endurance cycling had a negative effect. Our study used time trials instead of time to exhaustion as a marker of endurance performance. One important difference between time trials and endurance time is that during time trials the subject can make momentary reductions in power output in response to fatigue, and then increase power output later. Conversely, during endurance rides if the subject is momentarily unable to sustain power output the ride is over even if the subject is not fully exhausted.

Another study conducted by Wright et al. (7) found that CHO feeding prior to exercise had a beneficial effect. Their subjects ingested CHO at least one hour prior to testing. They also used endurance time to determine performance. The results of this study disagree with our findings that pre-exercise CHO feedings have no effect on endurance performance. However, in the Wright study the trial required a larger total time (~200 minutes versus ~75 minutes), which may have made the "topping off" of CHO stores prior to exercise relatively more important. Importantly, our subjects did not demonstrate the classic fall off in velocity that is characteristic of glycogen depletion (4).

We believe that this study is unique in that our marker of endurance performance and warm-up pattern is very similar to real world athletic competition. Competitive results are based on time to the finish line, not time to exhaustion. With this type of protocol our data may provide more meaningful results than previous studies. As such, our data may be interpreted as suggesting that pre-exercise CHO feedings are certainly not harmful competitively, and may convey competitively meaningful advantages during the closing stages of competition.

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APPENDIX A

INFORMED CONSENT

INFORMED CONSENT

THE EFFECT OF PRE EXERCISE FEEDING ON ENDURANCE PERFORMANCE

I, ______________________, consent to participate in a research study designed to determine if pre exercise carbohydrate ingestion affects endurance performance. I have been informed that I will be required to ingest a carbohydrate solution and a placebo before I am to undergo two subsequent time trials on a cycle ergometer. During the cycling trials I will have blood drawn from a fingertip to measure blood glucose and lactate levels. I have been informed that all of the testing will take place in the Human Performance Laboratory in Mitchell Hall at the University of Wisconsin-La Crosse. I have been informed that results of this study may be published or presented, with the confidentiality of all participants being upheld. I have been informed that a numbering system will be used to record all data to ensure confidentiality.

I have been informed of the risks involved with exercise testing, which include: dizziness, difficulty breathing, abnormal blood pressure, and in rare cases, cardiac arrest, stroke, or even death. The risk of exercise related complication is approximately 6/10,000 tests for all complications and 1/10,000 tests for serious complications. I do not know of any pre-existing conditions that would prevent me from participating in this study. I have been informed that the personnel involved in the testing procedures are CPR certified and that an excellent emergency protocol has been established.

I have been informed that through this study I may learn the benefits of using pre exercise carbohydrate ingestion to improve my endurance performance.

I have been informed that my participation in this research study is strictly voluntary and that I may withdraw at anytime for any reason without penalty. I have also been informed that the investigator will answer any questions I have regarding the study or its results.

In the unlikely event that any injury or illness occurs as a result of this research, the Board of Regents of the University of Wisconsin System, and the University of Wisconsin-La Crosse, their officers, agents and employees, do not automatically provide reimbursement for medical care or other compensation. Payment for treatment of any injury or illness must be provided by me or my third-party payor, such as my health insurer. If any injury or illness occurs in the course of research, or for more information, I will notify the investigator in charge. I have been informed that I am not waiving any rights that I may have for injury resulting from negligence of any person or the institution.

I have been informed that Carrie Petteys, a graduate student in the Adult Fitness/Cardiac Rehab program at UWL will be conducting the study. She may be reached at (608) 782-3057. The thesis chairperson will be Carl Foster, PhD, (608) 785-8687. Questions regarding the protection of human subjects may be addressed to the Chair of the UW-La Crosse Institutional Review Board for the Protection of Human Subjects. (608) 785-8124.

SIGNED: ____ DATE: __________

WITNESS: ____ DATE: __________

APPENDIX B

REVIEW OF LITERATURE

REVIEW OF LITERATURE

It has been well documented that muscle glycogen plays an essential role in endurance performance (3,11). An athlete with a high initial muscle glycogen concentration will be able to sustain endurance exercise for long bouts at a desired pace. The stores of muscle glycogen do not determine the pace, which is determined by maximal oxygen uptake (VO_2 max), but the sustainability of pace (3). Diet is directly related to glycogen stores, and if not regimented properly can lead to an overly elevated or depressed glycogen store that may be detrimental to endurance performance (3). Because glycogen is stored with water in muscle cells, the excess water accompanying the excess glycogen can cause a weight gain, which may negatively affect VO_2 max. On the other end of the spectrum, depletion of glycogen stores can increase time to fatigue, thus decreasing endurance performance. Costill et al. (3) evaluated the effect of free fatty acids (FFA) and insulin on the use of muscle glycogen as an energy source during exercise. During sub-maximal exercise, the body relies on lipid oxidation as an energy substrate. Therefore, increased levels of FFA would aid the body in decreasing glycogen utilization, sparing muscle stores. They also showed that elevated levels of glucose and resulting elevated levels of insulin increased carbohydrate (CHO) utilization, placing more dependence on the use of muscle glycogen for energy.

Because of its importance regarding muscle glycogen, ingestion of CHO before or during endurance exercise has been extensively studied. The results vary with the type of CHO used, when it is administered, and the type of performance markers used. Different studies have shown that CHO ingestion has an ergogenic effect on performance, has no effect on performance, or has a detrimental effect on performance.

Schabort et al. (15) studied the effect of a CHO rich meal prior to exercise. Seven subjects underwent testing on a bicycle ergometer in either a fasted state or having consumed a CHO rich (100 g) breakfast 3 hours prior. Subjects exercised at a workload requiring 70% VO_2 max. The time to exhaustion was significantly longer for the CHO trial as compared to the fasted trial. There were no negative effects on insulin or FFA concentrations. In fact, at the time of exercise insulin levels had returned to normal levels.

Chryssanthopoulos et al. (1) found that the beneficial effects of a pre-exercise meal high in CHO were further enhanced by using a carbohydrate-electrolyte solution during exercise. In this study, 10 subjects were required to complete 3 treadmill trials at 70% VO_2 max. Time to exhaustion was used as the performance marker. In the 3 different trials, the subjects ingested either a CHO rich meal or a placebo 3 hours prior to testing. During exercise in the CHO meal trial, the subjects were given a CHO solution. For the other trials they received either a CHO solution or a placebo. Exercise time was prolonged for both of the trials using CHO during testing, with the CHO meal trial being the longest. It was concluded that a CHO meal prior to exercise and CHO usage during exercise would serve to improve endurance performance.

Wright et al. (18) suggested that using CHO feedings before and during exercise proved most beneficial, supporting the work of Chryssanthopoulos et al. (1). Using time to exhaustion as the performance marker, 9 well-trained cyclists exercised at 70% VO_2

max. Four experimental trials were completed with the following testing variables: placebo, pre-exercise CHO feeding, during exercise CHO feeding, and before and during exercise feeding. All 3 CHO trials were significantly different than placebo according to time to exhaustion and work output. Performance was enhanced to the greatest degree when CHO was used in combination.

Further testing on the use of CHO feedings during exercise was completed by Coggan et al. (2). During prolonged high intensity exercise there is an excess demand placed on muscle glycogen stores. To test whether or not ingestion of glucose would reduce this demand, Coggan et al. had 7 well-trained individuals complete 2 trials of alternating bouts of moderate (65% VO_2 max) and high intensity (85% VO_2 max) exercise on a cycle ergometer. The subjects received either a CHO solution or a placebo 10 minutes after the start of exercise, and then every 30 minutes thereafter. Results showed that the CHO solution not only allowed subjects to exercise at a higher intensity (~75% VO_2 max) than the placebo, but also increased time to fatigue by ~30 minutes.

To test the effect of different types of CHO on endurance performance, Goodpaster et al. (9) compared placebo, glucose, a waxy starch, and a resistant starch during exercise testing. Ten competitive cyclists participated in 4 experimental trials. It was found that the 3 types of CHO increased CHO oxidation, and allowed the subjects to perform more work.

Fielding et al. (4) concluded that although blood glucose levels were maintained throughout exercise by ingestion of different doses of CHO, the use of muscle glycogen as a substrate was unchanged. Doses of 10.75 grams and 21.5 grams of CHO were administered at 30 and 60-minute intervals, respectively, throughout 4 hour cycling trials. No significant differences were found between doses or as compared to placebo relative to net muscle glycogen use.

Carbohydrate drinks are widely used among athletes. Flynn et al. (5) studied the effects of different types of CHO solutions on endurance performance. Eight well-trained cyclists completed 4 trials of 2 hours of cycling. During the trials the subjects consumed solutions of artificially sweetened water (placebo), maltodextrin and fructose, maltodextrin and high fructose corn syrup, and maltodextrin and glucose. No significant differences were found for the amount of work completed for any of the trials. The authors concluded that CHO use did not result in an improved performance.

Sparks et al. (16) studied the effect of CHO with different glycemic indexes. It had been suggested that ingestion of a low glycemic index (LGI) substance would result in a better endurance performance than a high glycemic index (HGI) substance. Subjects in this study ingested an LGI, HGI, or placebo 45 minutes prior to a 50-minute ride on a cycle ergometer. In opposition to earlier findings, Sparks et al. found that neither of the CHO substances improved performance over placebo.

Carbohydrates come in many different forms. CHO solutions containing fructose and glucose were studied by Hargreaves et al. (10) to determine if one form was superior to the other. According to the results found from 3 cycling trials to exhaustion, no significant difference was found between placebo, fructose, or glucose for performance indicators.

Palmer et al. (12) studied the effect of CHO ingestion immediately prior to exercise in 20 km time trials. Fourteen cyclists were recruited to participate in the study. Subjects ingested a placebo solution, or a solution containing ~39 grams of CHO. Ten minutes following CHO consumption the subjects completed a 5-minute warm-up, followed by a 20 km time trial. There were no significant differences found between the trials for power output and time to completion was the same for both. From this, the conclusion was that CHO consumption had no effect on performance.

Some earlier studies have found that pre-exercise ingestion of CHO has a detrimental effect on endurance performance. Foster et al. (6) used time to exhaustion in their cycling trials to indicate performance outcome. Sixteen subjects participated in 3 trials, consuming water, glucose, or a liquid meal containing protein, fat, and CHO 30 minutes prior to exercise. During exercise at 80% VO_2 max the glucose solution resulted in a 19% decrease in endurance performance time. Because of these results, it was noted that the increase in CHO oxidation served to hinder endurance performance.

Time to exhaustion has long been used as a marker for endurance performance (13,15). Because athletes do not compete only to exhaustion, this marker may not provide adequate information regarding training status for competitive athletes. It has been shown that there is a great deal of variability between trials when using fatigue time for a marker (13). Through more recent studies (13,14,15) it has been concluded that time trials may provide more real world results. Palmer et al. (13) determined the reproducibility of 20 and 40 km time trials. They found that laboratory performance times were highly correlated with those of road race times ($r = 0.98$). Schabort et al. (15)

supported these findings. They found that when subjects are able to choose their effort level, as opposed to a fixed workload, the test is more reliable. Subjects can use periods of high and low intensity to complete the trial, a tactic that is used by athletes competitively.

In conclusion, the use of CHO as an energy source before and during endurance exercise is widely accepted. The effect it has on endurance performance has been studied extensively, producing mixed results. The type, time, and dose of ingestion all seem to influence whether or not CHO is a performance enhancer. Different performance markers have also been used, with time trials seemingly the most reliable compared to actual competition.

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