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Carbohydrate ingestion and performance during prolonged endurance exercise

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CARBOHYDRATE INGESTION

AND

PERFORMANCE DURING PROLONGED

ENDURANCE EXERCISE

by

Michael J. Cendoma

An Abstract

of a thesis submitted in partial fulfillment

of the requirements for the degree of

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Thesis Advisor: Dr. Gary A. Sforzo

ABSTRACT

The purpose of this investigation was to examine the effects of different carbohydrate supplements on indicators of fatigue during prolonged endurance exercise. Five trained subjects (age: 33.6 ± 13.7 yr; weight: 77.6 ± 5.9 kg) exercised for 3 h at 60% VO_{2max} under four feeding conditions on a modified cycle ergometer. Each subject performed the 3 h test under each of the four feeding protocols: 1) Carbohydrate beverage delivering 0.5 g CHO/kg, 2) foodbar supplying 0.5 g CHO/kg, 3) carbohydrate beverage and foodbar combined, supplying 1.0 g CHO/kg and 4) placebo foodbar providing 0.24 g CHO/kg.

In each test the subjects were fed 20 min following the onset of exercise and at 20 min intervals thereafter. Blood was drawn at 20 min intervals throughout the tests and analyzed for plasma lactate and glucose. Brief (2 min) work capability efforts were given every 40 min. Oxygen consumption, respiratory exchange ratio, and rating of perceived

exertion (RPE) were also measured every 20 min during each test. A 4 X 4 (Treatment X Time) repeated measures ANOVA revealed no statistically significant interactions for dependent variables. Statistical analysis also revealed no significant differences in treatment main effects. Time main effects for the dependent variables were found to be not significant in all cases except for RPE and work capability, which reflected a general increase in exercise difficulty as time progressed through the 3 h period. Additionally, a trend for declining plasma glucose levels was observed across time, but was not found to be statistically significant.

These results indicate that an increase in perceived exertion and a decrease in work capability results from prolonged endurance activity regardless of the supplements taken during the activity. It appears that carbohydrate ingestion during exercise does postpone the onset of fatigue, but statistical analysis failed to show any significant differences between foodbars and beverages. The caloric contant of the placebo foodbar used during the investigation may explain why more significant findings were not found.

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CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

This is to certify that the Master of Science Thesis of

Michael J. Cendoma

submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Health Sciences and Human Performance at Ithaca College has been approved.

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DEDICATION

The time and effort put forth in the completion

of this project is dedicated to my parents

James M. Cendoma and Mary Jane Crane

for their continued understanding, love, and support

throughout my life

and

to the loving memory of my step-father

The Honorable

James B. Githler

who was unable to witness the accomplishments

in my life that he so influenced.

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INTRODUCTION

The 1940's and 1950's are credited with hosting the beginnings of the modern-day fitness revolution (Nieman, 1986). Since this time of increased health awareness, participation in athletic type activities has grown to include not only those who desire to compete, but also those interested in becoming more fit. Embodied within the human need to compete is the desire to bring about the best in one's self. As a result, athletes struggle to understand and optimize physical performance (Coyle, 1984).

Previous investigations have shown that the most effective means of improving physical performance is through prolonged, systematic exercise training (Coyle, 1984). Shown to increase muscle and liver glycogen stores, a well balanced diet and high carbohydrate pregame meal is also thought to be a standard for preparing athletes to compete (Coyle, Coggan, Hemmert, Lowe & Walters, 1985).

However, as demonstrated by Coyle and Coggan (1984) and Bronus (1990), with prolonged exercise at 60-80% maximum oxygen consumption (VO_{2max}), fatigue can result from an inability of endogenous carbohydrates to supply fuel to working musculature. Dietary ergogenic aids, as defined by Coyle (1984), are substances that, when ingested, result in a performance enhancement of up to 7 percent. Accordingly, ergogenic aids present an attractive avenue for athletes looking to combat fatigue and thus optimize performance.

Declining carbohydrate levels in the body may also lead to fatigue of another kind for individuals sensitive to changes in plasma glucose. Central nervous system fatigue typified by lightheadedness, nausea, and weakness may result from hypoglycemia (Coyle & Coggan, 1984). Previous studies indicate that the rate at which carbohydrates are digested during exercise hinders deliverance of valuable glucose to the blood thereby creating a condition of hypoglycemia.

Under such conditions the central nervous system would be deprived of irreplaceable fuel resulting in fatigue and performance impairment(Coyle, Coggan, Hemmert, Lowe & Walters, 1985; Gollnick, Pernow, Essen, Jansson & Saltin, 1981). By controlling feedings more recent investigations have shown rates of carbohydrate digestion that may aid in postponing muscle fatigue as well as the onset of hypoglycemia (Coggan & Coyle, 1987; Sherman, Costill, Fink & Miller, 1981; Sherman et al., 1989).

It has been well established that ingestion of a commercial carbohydrate beverage can aid endurance performance by postponing fatigue onset associated with carbohydrate depletion (Coyle & Coggan, 1984). More recently, carbohydrate ingestion through foodbar consumption has become a popular means for athletes seeking to delay carbohydrate related fatigue. It is logical to assume that muscles will perform better over a longer period of time when proper fuel sources are readily available. It is also logical to assume that foodbars provide the proper fuel and will enhance performance as well; however, this is not documented. Certainly, the solid state of a foodbar does raise the question of digestibility and the potential for energy contribution during an event. Many investigations have examined the effects of carbohydrate ingestion during prolonged exercise, but few have dealt with solid feedings as the carbohydrate source.

Both carbohydrate beverages and foodbars have become staples in the endurance athletes regimen (e.g., distance cycling). As a result, questions concerning the combination of these two products and the effects on performance are naturally raised. Specifically, manufacturers have found evidence that citric acid flavorings found in carbohydrate beverages may interfere with the digestion and absorption of foodbar ingredients (Maxwell, 1991). The purpose of this investigation is to study the effects of carbohydrate feedings on indicators of fatigue associated with carbohydrate depletion during prolonged endurance activity. This study will examine the effects of utilizing these products (both liquid and solid) alone and combined during exercise.

REVIEW OF LITERATURE

The following review contains literature that describes carbohydrates and their A) oxidation and uptake during exercise, B) effects on GI function, C) relationship to exercise related fatigue, and D) utilization in exercise feeding.

Carbohydrate Oxidation And Uptake

During Exercise

Total endogenous carbohydrate oxidation increases as the intensity of exercise increases through augmented glycogenolysis (Coyle & Coggan, 1984). Currently, less is known about the change in uptake and oxidation of plasma glucose as a result of increasing exercise intensity. Glucose uptake by the leg has been shown to increase with increasing exercise intensity to a maximum of 4 mMol/min (Felig & Wahrren, 1975). At 58% and 30% VO_{2max}, Ahlborg and Felig (1982) observed rates of glucose uptake of 3.6 mMol/min and 2.5 mMol/min, respectively. Also, Pernow and Saltin (1971) found that as exercise intensity increased from 51% to

64% VO_{2max} the oxidation rate of ingested glucose did not change. Although it was speculated that less of the ingested glucose was made available to the working muscles, the research indicates a possibility that the maximum rate of glucose uptake and oxidation does not change with increasing exercise intensity (Coyle & Coggan, 1984). Research has not quantified uptake values for exercise at moderate intensity but, as rationalized by Coyle and Coggan (1984), values could not be very high since the total carbohydrate requirements for exercise at moderate intensity can not be primarily supplied by plasma glucose. This rationale would be in agreement with past observations that plasma glucose may delay the onset of glycogen depletion related fatigue but cannot prevent the onset altogether due to the inability to act as a primary fuel source once glycogen stores are totally depleted.

The amount of energy derived from carbohydrates changes as intensity increases within the low intensity range of exercise (below 60% VO_{2max}). Within the moderate intensity range (60-80% VO_{2max}) and above the proportion of energy derived from plasma carbohydrate oxidation remains unchanged (Coyle et al., 1983; Ivy, Costill, Fink, & Lower, 1979). This may be because fats begin supplying more of the energy demands (Costill, Coyle, Dalsky, Evans & Hoopes, 1977). It is more likely, however, that insulin levels are not normally increased enough to cause an increase in uptake and oxidation of glucose by the working muscles. Under conditions involving carbohydrate ingestion during activity at moderate intensity insulin levels have been shown to increase 20-50%. As a result, supplementation may provide increased plasma carbohydrate concentrations and a mechanism by which muscle can more readily extract fuel from these concentrations. This may provide a route for muscles to delay fatigue by tapping into plasma concentrations thus sparing valuable glycogen stores (Coyle & Coggan, 1984).

If total carbohydrate oxidation remains unchanged and glucose uptake increases, muscle glycogen oxidation would then have to decrease. From this it appears that plasma glucose uptake does increase at some point throughout exercise. The question is whether the increased glucose uptake is a result of ingestion of glucose or, if, as some research has indicated, the uptake of glucose increases during later stages of prolonged exercise.

Investigations have reported that the uptake of glucose from plasma concentrations is related to the extent of glycogen depletion within the working muscles (Coyle & Coggan, 1984; Gollnick et al., 1981). Accordingly, working musculature was capable of extracting higher quantities of glucose at faster rates when in a state of glycogen depletion. Because plasma concentrations would be supplying more of the energy requirements, less stress would be placed on taxed muscle glycogen stores.

Gastrointestinal Function

Regulation

Throughout the past decade research has shown continually the benefits of carbohydrate ingestion during exercise, and hence, has prompted many to promote a carbohydrate feeding regimen. Still, fear of impaired GI function and related symptoms keep some athletes from utilizing carbohydrate ingestion as an ergogenic aid.

The duodenum is considered the most influential component in intragastric regulation. The duodenum is host to large numbers of receptors responsive to osmolality, amino acids, mono- and diglycerides, fatty acids, and carbohydrates. With the onset of food ingestion the gastroduodenal function is considered an "open loop" system, meaning, the effects of the ingested material directly influence activity in the gut. In the open loop system a rapid emptying phase is the direct result of the ingested material entering the stomach. Once the ingested material has entered the duodenum powerful receptors influence gastric activity via a feedback mechanism. In this "closed loop" system duodenal receptors, sensitive to the composition of the ingested material, indirectly influence gastric emptying (Brouns, Saris & Rehrer, 1987). The closed loop system of gastric regulation is ultimately responsible for rate of absorption. It is, therefore, primarily accountable for the efficacy of any ingested energy source (Rehrer, Beckers, Brouns, Ten Hoor, & Saris, 1989).

Factors Influencing GI Function

Temperature and Volume. Numerous factors influence the gastroduodenal activity and, hence, impose upon gastric emptying. Volume, temperature, energy density and acidity, exercise intensity, training status, as well as carbohydrate composition and osmolality have all been found to affect gastric emptying (Costill & Saltin, 1974; Foster, Costill, &

Fink, 1980; Neufer et al., 1986; Seiple, Vivian, Fox, & Bartels, 1983). Hunt and Spurrel (1951) found a linear relationship between elevated pressure in the stomach, resulting from increased stomach volume, and gastric emptying. This linear increase has been found to occur with consumption up to 600 ml (Costill & Saltin, 1974). Costill and Saltin (1974) also showed the temperature of ingested material to have an influence on digestion. Cold material tends to empty at higher rates than similar materials at warmer temperatures. Volume and temperature are examples of gastric emptying being regulated via the open loop system offered by Brouns et al. (1987).

Receptors within the duodenum react to osmolality, energy density and acidity of the ingested material and indirectly hinder gastric emptying through the closed loop system (Rehrer, Beckers, Bronus, Ten Hoor & Saris, 1989).

Exercise. According to Rehrer et al. (1989), studies examining the effects of exercise on gastric emptying are questionable because most utilized a repeated measures format in which carbohydrate sources were tested consecutively. Theoretically, gastric residue left over from the previous drink may have effects in the duodenum that will influence gastric emptying during administration of the new source. This is believed to produce inconsistencies in data collection. This investigation did, however, describe a trend toward gastric impedance with increased exercise intensity. Using a gastric tube inserted through the nasal cavity to remove and analyze gastric residue, Costill and Saltin (1974) reported that exercise has no effect on gastric emptying when work intensity was below 70% VO_{2max}. Although an attempt to control the effects of gastric residue was made, the effectiveness of this method is questionable as one subject was eliminated from the extrapolation of data due to abnormally high residue levels during rest intervals. However, 14 of the 15 subjects were included indicating the effects of gastric residue could be assumed to be equal throughout the population.

When the differences in the effects on GI function between trained and untrained athletes was examined, Rehrer and Beckers et al. (1989) found no significant difference in gastric emptying or gastric secretion within the first 60 minutes of exercise. Less trained runners complained of increased GI distress associated with carbohydrate feedings during practice when compared to more highly trained runners. GI distress is a subjective measure that may be affected by training level as well as individual sensitivity and the particular activity. GI problems were more frequently observed in runners when compared to cyclists. This indicates that a more accurate measurement of GI function may require more objectivity and tighter control over the activity and sensitivity of subjects.

Composition. Costill and Saltin (1974) and Foster et al. (1980) reported that emptying rates of ingested solutions increased as the glucose concentration increased within a given range. Beyond this range gastric emptying rates were adversely affected. Also, of the varying concentrations tested, the solution containing the lowest glucose concentration was released in a more continuous flow than the higher concentrations. Brener, Hendrix, and McHugh (1983) found that glucose concentrations from 5-25% supplied energy to the intestines at a consistent rate. Many of the investigations used commercial beverages as their carbohydrate source and gastric emptying rates could have been affected by sodium in these beverages. Isotonic solutions empty more rapidly, supposedly, due to sodium changing the osmolality and thus resulting in greater stimulation in the duodenum (Rehrer et al., 1989).

Glucose polymer solutions have been suggested to be an advantageous alternative to glucose solutions. Polymer solutions attempt to increase the flow of energy to the intestines without stimulating inhibitory duodenal receptors sensitive to concentration. Foster et al. (1980) found glucose polymer solutions to yield smaller gastric residue when compared to glucose solutions of the same concentration. Calculated delivery to the intestines also increased, presumably, due to polymer solutions resulting in a higher exit rate. Hypothetically, glucose polymer solutions, when compared to mono- and disaccharide solutions, are able to deliver greater energy to the small intestines without affecting gastric emptying rates due to their lower osmolality and diminished influence on receptors in the duodenum (Seiple et al., 1983).

Carbohydrate Related Fatigue

Muscle

Essen (1977) found muscle glycogen levels adequate to maintain moderately intense exercise (i.e., 60-80%

VO_{2max}) for approximately 2 h in individuals who were properly fed and well rested. Exercise bouts of shorter duration and lower intensity relied more on fats as the primary fuel source. In these instances muscle glycogen was oxidized more slowly (Essen, 1977; Pernow & Saltin, 1971). Under such circumstances, Essen (1977) found muscle glycogen depletion to take up to 10 hours. For this reason, athletes exercising at low intensities or short durations will not benefit from carbohydrate feeding as the exercise does not sufficiently tax muscle glycogen stores.

When exercise is performed at higher intensities (i.e., 80-100% VO_{2max}) muscle glycogen stores are depleted very rapidly. This rapid depletion of muscle glycogen is responsible for increasing lactic acid levels and other metabolic by-products that are the fundamental causes of fatigue (Pernow and Saltin, 1971; Gollnick et al., 1981).

Carbohydrate feedings have been shown to have their greatest endurance-enhancing effect when the primary cause of fatigue is muscle glycogen depletion (Fielding et al., 1985). The performance enhancement results from carbohydrate feedings maintaining plasma glucose stores and elevated oxidation rates even when endogenous glycogen stores have been heavily taxed. Hence, at a given intensity, individuals are able to exercise for longer periods of time before the onset of fatigue. This is not to be confused with enhancing performance by improving the ability of the athlete, or by allowing the athlete to compete at a greater intensity (Coyle et al., 1985).

Central Nervous System

Hypoglycemic conditions starve the central nervous system of energy and cause premature exhaustion and intense stress on the body. The extent of this stress and the exact mechanism is not fully understood and requires further study (Coyle & Coggan, 1984).

Sensitivity to decreased blood glucose is an important performance factor during prolonged endurance activity. Coyle et al. (1983) found symptoms of light-headiness, weakness, disorientation, and nausea in two of ten subjects during exercise tests to fatigue or 180 minutes, depending on which came first. These individuals were found to have low blood glucose concentrations (2.2-2.5 mMol) suggesting the symptoms were hypoglycemia related. Of these two subjects one was forced to halt exercise while the other was able to continue at a reduced work output. These tests involved subjects exercising for 2 h at the highest possible rate. Intensity was decreased in 100 kp/min decrements as subjects began to fatigue. Final fatigue was defined as 50% VO_{2max}.

Blood glucose levels are maintained as a result of a balance between tissue uptake and liver output. If an imbalance is created between these two systems blood glucose will react accordingly. Exercise brings about an increase in the liver output as well as an increase in muscle uptake of glucose. Initially, the system maintains a balance, however, as exercise intensity reaches 60-80% VO_{2max} and duration extends beyond 2 h muscle uptake begins to exceed liver output as liver glycogen stores become depleted. Gluconeogenesis has been shown to increase with onset of exercise, however, at moderate to intense exercise it fails to compensate for the imbalance (Coyle & Coggan, 1984). As a result, the two systems are no longer able to maintain equilibrium and blood glucose levels fall (Ahlborg & Felig, 1982). When liver and muscle glycogen reach a severely depleted state, blood glucose levels may fall to within the range of frank hypoglycemia (i.e., 2.5 mMol/L) and performance suffers greatly even though oxygen is in sufficient supply and the potential energy from fat is abundant (Ahlborg & Felig, 1982; Coyle et al., 1983; McArdle, Katch, & Katch, 1991).

Blood glucose levels that fall within the range of frank hypoglycemia result in fatigue that is apparently related to CNS dysfunction. Because the nervous system is responsible for muscle fiber recruitment, dysfunction could have a grave impact on work capabilities.

Christensen & Hanson (1939) found that at the point of hypoglycemia, subjects reported subjective symptoms of lightheadedness, weakness, and nausea. Later investigations found that with the ingestion of glucose and a rest period, subjective complaints disappeared and subjects were able to continue exercising (Felig, Cherif, Minagawa & Warren, 1982). Coyle et al. (1983) suggested that preventing a hypoglycemic state during exercise may allow subjects sensitive to declining blood glucose to exercise longer without onset of symptoms associated with CNS fatigue.

The subjective symptoms associated with frank hypoglycemia are accompanied by an early onset of fatigue. These symptoms are not associated with objective measures and tend to improve with the ingestion of glucose. This suggests that fatigue can be due, in part to CNS dysfunction. The level of dysfunction appears to be a product of individual sensitivity to declining blood glucose levels (Coyle & Coggan, 1984).

Exercise Feedings

Effects On Performance

Exercise capacity at intensities between 60-80% of maximal oxygen consumption is limited by carbohydrate reserves (Wright, Sherman, & Dernbach, 1991). Over the past 50 years, investigations have shown repeatedly that exercise at moderate intensities cannot be maintained when carbohydrate reserves become depleted (Bergstrom, Hermansen, Hultman, & Saltin, 1967; Bergstrom & Hultman, 1967; Christensen & Hansen, 1939). It is believed that exercise capacity is adversely affected by a decline in the carbohydrate reserves of working muscles (Bergstrom & Hultman, 1967).

Because carbohydrate depletion has been shown to affect performance, nutritional tactics aimed at increasing carbohydrate stores, and the availability of those stores, are seen as viable strategies for performance enhancement (Wright et al., 1991). Recent literature has demonstrated that carbohydrate feeding throughout exercise can be beneficial in delaying carbohydrate depletion related fatigue (Coyle et al., 1983; Ivy et al., 1983).

Originally, carbohydrate feeding during exercise was frowned upon due to fear of impaired GI function and the belief that blood glucose was oxidized too slowly to be of benefit (Brouns, Saris & Rehrer, 1987; Coyle, 1984). However, studies have supported the idea that carbohydrate feeding during exercise may delay fatigue resulting from carbohydrate depletion without the onset of GI symptoms (Costill & Saltin, 1974; Coyle et al., 1983). Carbohydrate feeding may also delay CNS fatigue in individuals sensitive to declines in blood glucose (Coyle, Coggan, Hemmert, & Ivy, 1986; Coyle et al., 1983; Christensen and Hansen, 1939).

The most recent proposed mechanism by which carbohydrate ingestion delays fatigue suggests that a substantial fuel source is maintained when stored fuel has become depleted (Mason, McConell, & Hargreaves, 1993).

Glycogen Sparing

There is recent evidence that ingestion of carbohydrates enhances performance during moderate intensity, extended exercise duration by supplying the working muscles with a fuel source following depletion of endogenous stores (Coyle et al., 1983; Wright et al., 1991; Coggan & Coyle, 1988; Coyle, Coggan, Hemmert & Ivy, 1986; Murray, Paul, Seifert & Eddie, 1991). Current literature agrees that the mechanism for this delay is ingested carbohydrate sources that maintain elevated plasma glucose levels and oxidation rates when muscle glycogen is compromised. Hence, the ingested source allows valuable fuel to be made available and delivered to working muscles when the endogenous supplies, vital to exercise, are low (Coggan & Coyle, 1987; Coyle et al., 1985; Coyle et al., 1983; Hargreaves & Briggs, 1988). The term glycogen sparing may be attached to this mechanism, however, this expression can create confusion. Past beliefs were that the elevated plasma glucose level from an ingested carbohydrate source spared muscle glycogen use by supplying the working muscle with an alternate fuel source. An important, but sometimes overlooked consideration is that endogenous stores are the muscles' fuel of choice. It is speculated that supplementary sources will not be used until endogenous stores become depleted and are unable to supply energy requirements. When stored glycogen becomes dangerously low, there is an increase in glucose extraction by the muscle from plasma to maintain work output and delay fatigue. This increased rate of extraction, however, is not significant until after stored glycogen is depleted (Coyle & Coggan, 1984).

Some earlier investigations failed to show that ingestion of glucose during exercise significantly affected the onset of fatigue (Ahlborg & Felig, 1976; Pirnay, Lacroix, Mosora, Luyckx, Lefebvre, 1977a; Pirnay, Lacroix, Mosora, Luyckx, Lefebvre, 1977b). These investigations utilized exercise intensities below 50% (VO_{2max}) and failed to extend exercise duration to the 2-3 h mark required to significantly tax muscle and liver glycogen stores. Coyle et al. (1983) investigated the effects of carbohydrate feedings during prolonged strenuous activity. In this investigation a subgroup exercising for 180 minutes at 70-80% of VO_{2max} without carbohydrate feeding did not have a significant drop in blood glucose levels. This suggested that exercise of durations below 180 minutes, even at moderate intensity, failed to tax endogenous glycogen stores to the point that the working muscles relied on plasma glucose to meet energy demands.

Prior To Exercise

Previous research has demonstrated that dietary consumption and training habits affect glycogen stores (Costill & Miller, 1980; Sherman et al., 1981). Successive bouts of moderate to heavy exercise over a given training period may be responsible for a gradual depletion of glycogen stores even though dietary carbohydrate intake throughout this training period is within recommended dietary levels. This gradual depletion is thought to account for the "plateau" effect endurance athletes report following extended periods of intense training. "Plateauing" is characterized by increasing difficulty with performing routine exercise and subjective reports of "staleness" (McArdle et al., 1991). McArdle et al. (1991) reported that running 10 miles per day for three successive days depleted muscle glycogen stores in the quadriceps of runners. This was observed even though a high dietary carbohydrate intake was maintained (40-60% of total dietary calories).

Some authors have reported a more rapid decline in performance when carbohydrates were ingested just prior to the onset of moderate intensity exercise (Coyle & Coggan, 1984). This observation is thought to be caused by a decline in blood glucose associated with an insulin release, and an exercise induced increase in the rate of glucose extraction. This effect may lead to a state of hypoglycemia and CNS dysfunction.

Earlier onset of fatigue is also believed to be due to depressed liver glucose output and fat oxidation following carbohydrate ingestion prior to exercise. Of question, however, is the time at which feeding prior to exercise will result in these undesirable physiological events and negatively affect performance. Solid as well as liquid feedings have been found to have no adverse effects on exercise performance when ingested 30 minutes prior to exercise (Girandola, Wisewell, Khodiguian, Shottel, & Hecker, 1984). Following the onset of exercise, catecholamine release, proportional to the intensity of exercise, suppresses insulin secretion from the pancreas (Bronus et al., 1987). For this reason hyperinsulinism and the associated drawbacks may be avoided if glucose ingestion begins after the onset of exercise.

During Exercise

Diet and training practices prior to exercise are important factors in determining the muscle and liver glycogen levels at the onset of exercise (Costill & Miller, 1980; Sherman et al., 1981). Carbohydrate feedings during exercise are intended to furnish the working musculature with a readily available fuel source once endogenous stores are depleted. Although plasma glucose has been shown to delay fatigue, investigations have failed to show that carbohydrate feeding reverses or prevents fatigue. Evidence suggests that performance is irreversibly diminished with depletion of muscle glycogen stores due to the inability of alternate systems to provide sufficient and timely energy. Specifically, the transport of plasma glucose to muscle has been found to be too slow to act as an alternate primary fuel source (Coyle & Coggan, 1984; Coyle et al., 1983).

Efficacy of Supplement

Brouns et al. (1987) proposed that an ideal beverage for athletes is one that allows for rapid gastric emptying to provide fast rehydration and is a substantial energy source. The first point has been touched on previously, but a beverage providing a substantial energy source is of particular interest. Hunt (1960) showed somewhat faster gastric emptying rates with complex carbohydrates. Sports beverages are typically simpler forms such as glucose or sucrose. Solid feedings during exercise, via foodbar for example, contain a more complex carbohydrate make up and hence, may provide more continual flow of greater energy to the intestines than beverages. What if the foodbar was used in conjunction with the beverage? Would this cover all the bases and better protect the athlete from premature fatigue resulting from carbohydrate depletion? Maxwell (1991) recommends the use of a foodbar product with water as citric acid used to flavor sports drinks is believed to hinder the digestion of the foodbar.

The introduction of foodbars as an ergogenic aid has complicated an already complex avenue of sports nutrition. The physiological benefits of carbohydrate ingestion during exercise are well established, but further investigations to uncover the questions surrounding the application of these products are necessary.

METHODS AND PROCEDURES

The following sections describe the procedures to examine the effects of carbohydrate feedings on performance during endurance activity. Subject selection, testing procedures and protocols, ergometer design and data analysis are outlined within this chapter.

This investigation is designed to study physiological indicators of fatigue in cyclists during extended exercise bouts while consuming different forms of carbohydrates. Specifically, oxygen consumption, respiratory exchange ratio, heart rate, work capability, rating of perceived exertion, blood lactate and glucose will be monitored at 20 minute intervals throughout a 3 h exercise period at 60% VO_{2max}. Work capability tests will be interspersed at 40 minute intervals throughout the test rides to examine potential changes throughout the exercise period.

Subjects will complete four 3 h test rides. During each ride, subjects will ingest one of the following carbohydrate supplements: 1)foodbar and water, 2) carbohydrate beverage, 3) foodbar and carbohydrate beverage combined, and 4) placebo foodbar and water. Subjects will schedule the test rides 7 days apart.

Each of the 3 h rides will be performed on a cycle ergometer adapted with adjustable drop handle bars, racing style saddle, and clipless pedals to more closely replicate actual riding conditions. Seat height will be set using 109% of symphysis pubis height as measured by marking this location on a wall and measuring. This measurement will then be used to control seat height throughout performance tests.

Subject Selection

Subjects will be recruited from the Ithaca College and Cornell University campuses as well as the Ithaca community by posting announcements and making group presentations. All interested subjects will attend an organizational meeting designed to outline subject involvement, complete an informed consent form (Appendix A-1) and a medical history/health habit questionnaire (Appendix A-2).

Diet

Dietary intake will be partially controlled for three days prior to each testing session. A menu with examples of high carbohydrate food stuffs will be provided to each subject. Menu items will be comprised of a diet consisting of 58% carbohydrate, 30% fat, and 12% protein. Subjects will be asked to refrain from eating and consume only noncaffeinated noncaloric beverages for 12 h before testing.

Graded Exercise Testing

Prior to the graded exercise test, a 24 hour health history questionnaire will be completed and reviewed (Appendix A-3). Blood samples will then be drawn using a finger stick. Samples will be drawn into a collection tube and analyzed for baseline plasma lactate (YSI Model 27 Industrial Analyzer, Scientific Division, Yellow Springs Instrument Co., Inc., Yellow Springs, OH, 45387), and glucose levels (Stat Test/Stat Spin, Stat Chem, Inc., Bohemia, NY, 11716). Exercise tests will begin by having the subject establish a comfortable pedal cadence during a no-load, 2 minute warm-up on the modified cycle ergometer. Following the warm-up, the resistance will be increased 0.5 kp every 2 min. until exhaustion to determine VO_{2max}. Heart rate (Polar Pacer/C.I.C. heart monitor, Hempsted, NY, 11550), RPE, and oxygen consumption will be recorded at the 2 minute mark in each stage. The workload for subsequent endurance rides will correspond to 60% VO_{2max}. The workload will be calculated using the following equation: VO_{2max} (ml/min) = 2 * Work load (kpm/min) + 3.5 ml/kg/min * body weight (kg) (American College of Sports Medicine, 1991).

Performance Testing Procedures

Following graded exercise testing, subjects will schedule testing sessions and be given pre-exercise test instructions (Appendix A-4). These instructions outline guidelines for subjects to follow prior to each testing session.

In order to reduce dehydration and promote thermal regulation, the testing procedure will allow controlled fluid intake of a carbohydrate beverage or water at 20 min. intervals depending on the protocol. Subjects will be permitted to watch television, read, or listen to music as psychological distractions throughout the tests.

Feedings

Supplement feedings will be counterbalanced over the four performance tests. Prior to each test subjects will complete a 24 h history questionnaire (Appendix A-3). The 24 h questionnaire will be used as an indication of whether the testing session should continue based on the subjects sleeping, eating, physical participation and subjective feelings throughout the past 24 h period. Following the completion of the 24 h history questionnaire, a pretest blood sample will be drawn from the nondominant hand using a finger stick. Glucose and lactate will be analyzed from this sample. Subjects will then proceed with testing through the four conditions in the assigned order as they are outlined below, allowing seven days between each test.

1. During the foodbar protocol subjects will be fed a high carbohydrate source providing 3.5 kcal/g; approximately 72% carbohydrate, 19% protein, and 9% fat (PowerFood, Inc., Berkeley, CA, 94709) The first feeding will be 20 minutes prior to the onset of exercise and the remainder at 20 minute intervals throughout the 3 h endurance ride. Quantities for each 20 minute feeding will be calculated as .50 g/kg of body weight. This protocol also involves drinking eight ounces of water during foodbar feeding.

2. During the fluid replacement session subjects will ride and consume 6% carbohydrate solution (Quaker Oats, Chicago, Ill, 60604-9003) supplying .50 g/kg of body weight, 20 minutes prior to exercise onset and at 20 minute intervals throughout the exercise bout.

3. A third feeding regimen will involve the ingestion of both the high carbohydrate source and 6% solution. This feeding schedule combines the foodbar and fluid replacement protocols outlined above and yields 1.0 g/kg of body weight. In this condition, water intake will be replaced by the ingestion of the carbohydrate beverage.

4. The control group will consume a placebo foodbar and water similar to the foodbar protocol. These bars will be derived from a combination of flour, corn starch, NutraSweet brand sweetener, nutmeg, and food coloring that will yield approximately 3.7 kcal/g; 78% carbohydrate, 11% protein, and 11% fat. The amount of placebo ingested will be calculated in the manner described for the foodbar protocol (#1 above).

In all conditions subjects will cycle at 60% of VO_{2max} for 3 h or until exhaustion. A subject will be considered exhausted if work output decreases by 30% of VO_{2max} (i.e., from 60% to 30% VO_{2max}).

Heart rate, oxygen consumption, rating of perceived exertion (Appendix A-5) and pedal cadence will be monitored continually throughout the first 20 minutes of exercise to ensure exercise intensities have been correctly calculated. During the remainder of the exercise, oxygen consumption, respiratory exchange ratio, rating of perceived exertion, lactate production, and heart rate will be monitored every 20 minutes.

Work capability tests will be performed every 40 min. throughout the exercise session. These tests will involved a 2 min. all-out exercise bout with the ergometer resistance set at a workload determined to elicit 90% VO_{2max}, while pedalling at a maximum cadence. Revolutions will be counted to calculate maximum work capability as a product of force (kp) and total distance (rev*m/rev). Following each work capability test subjects will exercise at 50% VO_{2max} for 2 min. before returning to 60% VO_{2max}.

Oxygen consumption will be determined using open circuit spirometry. Expired gases will be collected and analyzed every 20 min. for 2 min. Blood samples will also be taken at 20 min. intervals throughout the test. Samples will be analyzed for glucose and lactate levels. Heart rate and record of perceived exertion will be recorded at 20 min. intervals.

Following completion of each exercise session subjects will be instructed in proper stretching techniques in an attempt to limit soreness associated with the test ride. Heart rate will be monitored for at least five minutes after exercise to ensure proper recovery.

Statistical Analysis

A 4 X 4 (time X treatment) repeated measures analysis of variance will be used to test for difference between the dependant variables which include blood lactate concentration, blood glucose concentration, work capability, heart rate, rating of perceived exertion, oxygen consumption and respiratory exchange ratio. Significance will be set at $p < 0.05$. Post-hoc testing will use t-tests with Bonferoni adjustment.

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Preface to the Research Manuscript

Following acceptance of the previous proposal and prior to the onset of the investigation a number of factors were modified. These modifications are as follows:

At the onset of this experiment 14 male subjects and 1 female subject who classified themselves as trained cyclists were involved in the investigation. Five of the subjects were dismissed due to noncompliance with scheduled testing, 3 were required to withdraw from participation due to schedule conflicts, and 2 dropped out due to sickness. Five subjects, 4 male and 1 female, ultimately completed the study.

Upon further review of the methodology, it was determined that in order to limit hyperinsulinism feedings should begin 20 min following the onset of exercise rather than 20 min prior to exercise onset.

CARBOHYDRATE INGESTION

AND PERFORMANCE

DURING PROLONGED ENDURANCE EXERCISE

A Research Manuscript

submitted in partial fulfillment of the

requirements for the degree of

Master of Science

in the School of Health Sciences and Human

Performance at

Ithaca College

Introduction

Historically, the belief was that a well balanced diet, high in carbohydrate (CHO), was sufficient to supply all the nutritional needs of an athlete at any level (Coyle, Coggan, Hemmert, Lowe & Walters, 1985). More recently, some have suggested that for selected athletes, energy requirements may not be sufficiently met through diet alone (Bronus, 1990). It is now well established that supplemental CHO ingestion during exercise bouts lasting 2 or more hours at 60-80% maximum oxygen consumption (VO_{2max}) plays a major role in delaying the onset of fatigue associated with endogenous glycogen depletion (Coyle, Hemmert & Ivy, 1986; Coyle, Hagberg, Hurley, Martin, Ehsani & Holloszy, 1983; Coyle, 1984; Carter & Gisolfi, 1989; Mason, McConnel & Hargreaves, 1993).

Initially, during exercise, a balance between increased tissue uptake and liver glycogen output results in maintenance of plasma glucose levels.

Although oxidation of plasma glucose does increase with the onset of exercise, a more significant increase is observed when endogenous glycogen stores become depleted (Mason et al., 1993). This suggests that stored glycogen is the preferred CHO source as long as it is available.

As exercise intensity increases with the low intensity range (30-50% VO_{2max}), the rate of muscle and liver glycogen oxidation increases in response to a heavier energy demand (Pernow & Saltin, 1971). If exercise intensity and duration increase, declining liver glycogen stores result in a decreased liver output of glucose; muscular demand then begins to exceed liver oxidation. During long duration exercise, working muscles oxidize plasma glucose at a higher rate to compensate for the declining glycogen stores (Mason et al., 1993). This may be a natural mechanism through which working muscles conserve the diminishing glycogen stores. Though gluconeogenesis has been shown to increase with exercise, it fails to compensate for the deficit; hence, plasma glucose levels begin to decline (Coyle & Coggan, 1984).

Typically, exercise at 60-80% VO_{2max} lasting more than 2 h significantly depletes both muscle and liver glycogen (Wright, Sherman & Dernbach, 1991). At this stage, performance is severely hampered even though oxygen and the potential energy from fat are in sufficient supply (Ahlborg & Felig, 1982; Coyle et al., 1983; McArdle, Katch & Katch, 1991). Diminishing CHO stores may also adversely affect performance through a central nervous system effect (Coyle & Coggan, 1984). Christensen and Hansen (1939) reported subjective symptoms of lightheadiness, weakness, and nausea associated with plasma glucose depletion. Later investigations reported these findings and also found that these symptoms disappeared following CHO ingestion (Coyle et al., 1983). CHO feedings that are readily digestible and absorbed delay fatigue by furnishing the working muscle and central nervous system with a readily available fuel source when glycogen stores are low (Costill & Miller, 1980).

Volume, temperature, density and acidity as well as CHO composition and osmolality each influence substrate availability when a CHO supplement is used (Hunt & Spurrel, 1951; Costill & Saltin, 1974; Rehrer, Beckers, Brouns, Ten Hoor & Saris, 1989). It has been found that a 6-8% CHO solution in volumes of 0.50-1.0 g/kg of body weight at 20-30 min intervals provide the most continuous contribution of CHO from the gut (Costill & Saltin, 1974; Foster, Costill & Fink, 1980; Coyle, 1984). Because CHO ingestion is known to have an ergogenic effect, athletes are continually striving to optimize utilization of these supplements. It is not so much a question of whether to ingest CHO during exercise, but rather, in what form and in what quantity. Past research has centered on beverages as the main source of ingested CHO. Recently, solid feedings of complex CHO sources have been introduced to endurance athletes. Manufacturers claim these sources have been reported to supply a more continuous supply of CHO over a prolonged exercise bout. Because the CHO beverages also provide for proper hydration during exercise some may be inclined to use the two sources together to maintain CHO levels and to promote fluid balance and thermal regulation (Coyle, 1984). Maxwell (1991), however, reported that the citric acid component of beverages may hamper digestion of the solid food feedings and therefore suggests water should be used in conjunction with solid feeding products.

It is important to athletes and their performance to understand the value of solid feedings during exercise and, more importantly, to know if solid and liquid feedings interact to improve or potentially hinder performance. Therefore, the purpose of this investigation was to examine the effects of solid and liquid CHO feedings on prolonged exercise performance.

Methods

Five well trained subjects, four males and one female, (33.6 yrs ± 13.7; 77.6 kg ± 5.9) volunteered to participate. All subjects signed an informed consent document after being informed of the risks involved in participation (Appendix A-1). The study was approved by the Human Subject Research Committee of Ithaca College.

Subjects VO_{2max} was first tested using a standard graded cycle ergometer test. The results of these tests were used to determine submaximal workloads and pedal cadence during the experimental test rides. Bodyguard 990 ergometers were used and fitted with an adjustable drop handle bar, clipless pedals, and a racing style saddle for all rides.

Subjects first completed a graded exercise test to establish initial measures. Subjects were then tested on four separate occasions seven days apart. During the 24 h period prior to each testing session diet, fluid intake, and exercise were standardized. For each of the four test sessions, subjects rode the cycle for 3 h at 60% VO_{2max} workloads. Feeding began 20 min following the initiation of exercise and continued in 20 min intervals throughout the test. One test ride under each of the following four feeding protocols were completed by each subject for a total of four test rides:

1. Foodbar- During these tests subjects were fed a solid high CHO source providing 3.5 kcal/g (PowerFood, Inc., Berkeley, CA, 94709). Approximately 72% of these calories were derived from CHO, 19% from protein, and 9% from fat. Quantity and frequency for each feeding were established according to 0.5 g of CHO/kg of body weight every 20 min. Eight ounces of water was also ingested with foodbar consumption every 20 min.

2. Fluid Replacement- These tests involved subjects consuming a 6% CHO solution supplying 0.5 g of CHO/ kg of body weight every 20 min (Quaker Oats, Chicago, Ill,

60604-9003). This delivered 3.3 kcal/g (100% from CHO).

3. Combination- Under these conditions subjects consumed both the foodbar and CHO solution according to 0.5 g of CHO/kg of body weight to yield 1.0 g of CHO intake/kg of body weight every 20 min.

4. Placebo- These tests involved consumption of a placebo foodbar derived from a combination of flour, corn starch, NutraSweet brand sweetener, nutmeg, and food coloring. The placebo bar yielded approximately 1.85 kcal/g; 78% CHO, 11% protein, and 11% fat. This was administered by weight (g) at the same ratio as calculated for the foodbar test.

A work capability test was performed every 40 min during the 3 h of exercise performance rides. These tests consisted of a 2 min all out effort at the resistance that produced 90% VO_{2max} during the initial graded exercise test. During this test subjects were instructed to pedal as hard as possible and a measure of total pedal revolutions was recorded. Pedal revolutions during the work capability test were used to indicate potential work capability. These tests were followed by a 2 min recovery period during which the subjects rode at 50% VO_{2max} before resuming the test ride at 60% VO_{2max}.

Prior to exercise body weight was recorded and a blood sample was drawn from the index finger of the non-dominant hand following 15 min of seated rest. Subjects were then fitted with a heart rate monitor and gas collection mask. The 3 h exercise bout was performed in an environmentally controlled laboratory (22-25°C). During this time, finger sticks and plasma analysis was repeated at 20 min intervals. Blood samples taken prior to and during exercise bouts were analyzed for plasma lactate (YSI Model 27 Industrial Analyzer, Scientific Division, Yellow Springs Instrument Co., Inc., Yellow Springs, OH, 45387) and glucose (Stat Test/Stat Spin, Stat Chem, Inc., Bohemia, NY 11716). Oxygen consumption, respiratory exchange ratio, and heart rate were also recorded at these time points.

Immediately following exercise, subjects exercised for four minutes at a comfortable submaximal level to cool down. During this time heart rate was monitored to ensure proper recovery. Lastly, postexercise body weight was recorded and subjects were encouraged to stretch and rehydrate.

Repeated measures 4 X 4 (treatment by time) analyses of variance were used to analyze data. Blood lactate, blood glucose, work capability, heart rate, rating of perceived exertion, oxygen consumption and respiratory exchange ratio were dependant variables. Significance was accepted at the $p < 0.05$ level. When a significant F-value was obtained, location of differences between means was achieved with Bonferoni adjusted paired t-tests.

RESULTS

Blood Lactate

The 4 X 4 (treatment X time) repeated measures analysis of variance for lactate revealed no significant interaction ($F_{3,12}$ = 0.25). Analysis of time ($F_{3,12}$ = 2.24) and treatment ($F_{9,36}$ = 0.94) main effects also showed no significant differences. Table 1 of Appendix B-1 displays these results.

Blood Glucose

Statistical analysis for glucose failed to show any significant interaction ($F_{3,12}$ = 0.44). F values for time ($F_{3,12}$ = 1.35) and treatment ($F_{9,36}$ = 0.65) main effects also failed to indicate any significant differences. These results are displayed in Table 2 and Figure 1 of Appendix B-1.

Work Capability

Interaction ($F_{3,16}$ = 0.16) and treatment ($F_{9,48}$ = 0.99) main effect for work capability were not found to be significant. The F value for the time main effect ($F_{3,16}$ = 12.99) was found to be statistically significant ($p < 0.05$). When the means at each time interval were compared to the mean of initial measures (time = 0), Bonferoni adjusted paired t-tests failed to show significant results at 40 min. However, significant findings were found when 80 min (P = 0.0152), 120 min(P = 0.0053), and 160 min (P = 0.0021) were compared to initial measures. Comparison between 120 min and 160 min of exercise failed to show significant results (P = 0.259). Tables 1, 2a, and 2b of Appendix B-2 display these results.

Heart Rate

Statistical analysis of heart rate revealed no significant interaction ($F_{3,16}$ = 0.16). Time ($F_{3,16}$ = 0.20) and treatment ($F_{9,48}$ = 0.67) main effects also showed no significant differences. These results are displayed in Table 1 of Appendix B-3.

Rating of Perceived Exertion

Statistical analysis for interaction of perceived exertion revealed no significant differences ($F_{3,16} = 0.18$). Treatment ($F_{9,48} = 1.05$) was also not found to be significantly different. The F value for the time main effect of perceived exertion ($F_{9,48} = 34.74$) was found to be statistically significant ($p < 0.05$). When the mean RPE score at 40 min was compared to the mean RPE at all other time intervals using a Bonferoni adjusted paired t-test significant differences were found at 80 min ($p = 0.0003$), 120 min ($p = 0.0001$), and 160 min ($p = 0.0001$). Significant differences were also found when mean RPE values at 120 min. were compared to those at 160 min ($p = 0.0001$). These results are displayed in Tables 1, 2a, and 2b of Appendix B-4.

Oxygen Consumption

Statistical analysis failed to show significant oxygen consumption interaction ($F_{3,12} = 0.11$). Time

($F_{3,12}$ = 1.43) and treatment ($F_{9,48}$ = 0.60) main effects also showed no significant differences. These results are displayed in Table 1 of Appendix B-5.

<u>Respiratory Exchange Ratio</u>

Respiratory exchange interaction showed no significant differences ($F_{3,12}$ = 2.25). Time ($F_{3,12}$ = 1.68) and treatment ($F_{9,36}$ = 0.78) main effects also showed no significant differences. Table 2 of Appendix B-5 displays these results.

Discussion

According to these results, it seems that neither the CHO foodbar or beverage was more beneficial to performance. Additionally, it appears that neither of the CHO supplements was more beneficial than the placebo when compared individually or in combination. This contradicts most previous literature (Wright et al., 1991; Mason et al., 1993).

In view of recent manufacturer's claims, one might expect to find a significant difference between the beverage and foodbar conditions. Coyle (1984) prescribed 0.5 to 1.0 g of CHO/kg of body weight from a 6-8% CHO source ingested at 20-30 min intervals to maximize the benefits of CHO supplementation. In either the beverage (0.5 g of CHO/kg of body weight at 20 min intervals) or foodbar (0.5 g of CHO/kg of body weight at 20 min intervals) conditions subjects met these requirements. These guidelines were also met under the combined condition that involved 1.0 g of CHO/kg of body weight at a 20 min interval.

Perhaps CHO intake beyond a given amount is not of any further benefit. A study by Murray et al. (1991) examined how varying rates of carbohydrate ingestion affected physiological, sensory, and performance responses of ten subjects. The investigation involved 2 h of cycling exercise while ingesting carbohydrate at rates of either 26, 52, and 78 g/h. The authors concluded that once a minimum rate of CHO intake had been reached further ingestion was of no additional benefit. Furthermore, when investigating the effects of physical form and composition of the supplements on performance Mason et al. (1993) found that CHO supplements of different physical form but equal CHO content produced similar insulin and glucose responses throughout exercise. This would help explain why there is no difference in performance regardless of how the CHO were ingested, or how much was ingested above 0.5 g of CHO/kg of body weight.

Amount, form and composition may have all been factors in limiting the significant findings of this investigation; however, one must wonder why the placebo protocol was not significantly different from the other treatments. The placebo foodbar did contain calories (1.85 kcal/g) equal to about one-half of those in the foodbar treatment, and 78% came from CHO. This caloric value may have been sufficient to prevent a significant difference in the onset of fatigue between the placebo and treatment conditions. Still, Figure 1 of Appendix

B-1 displays a trend that suggests when exercising under the placebo condition, plasma glucose levels may have initially declined more rapidly compared to the other conditions. This trend, however, is minimal and is not statistically validated.

Coyle (1984) reported carbohydrate intake of 0.5g-1.0 g CHO/g of bw from a 6-8% solution was the most effective way to ingest carbohydrates to delay the onset of fatigue. Both the CHO foodbar and CHO beverage supplied carbohydrates within this range. However, Figure 1 of Appendix B-1 indicates a trend for a more rapid increase in blood glucose with the ingestion of the beverage compared to the foodbar and foodbar/beverage groups. Bronus et al. (1987) suggested that in order to maintain optimal gastric emptying rates during exercise solids should be avoided and liquids should be limited to those that do not contain fat and protein. If the trend in the present data is true then it may be that the fat and protein composition of the foodbar hindered availability of glucose relative to the beverage.

As exercise continues beyond 80 min, the capability to produce work during a maximum effort is expected to be less than at the onset of exercise. This is confirmed in an investigation by Wright et al. (1991) who examined the effects of no carbohydrate feeding, pre-exercise carbohydrate feeding, carbohydrate feeding during exercise, and the combination of carbohydrate feedings before and during exercise on metabolic responses during exercise and on exercise performance. The authors reported a significant treatment main effect for work output; however, power output was still shown to decrease over time in all groups. This decrease in performance with time was again confirmed in the present study.

At the same time, according to the present findings, exercise is perceived to be harder as time goes on. Similar results have been reported by Murray et al. (1991) and Wright et al. (1991). In both of these investigations rating of perceived exertion was shown to increase over time, but no differences among treatments were observed. Table 2b shows that when mean RPE values at 120 min were compared to 160 min significant differences were reported. These results suggest that not only was exercise perceived to be harder at each time interval after 40 min (see Table 2a of Appendix B-4) but that RPE continually increased between time intervals until the end of the 3 h exercise period.

Declines in work capability and increases in the rating of perceived exertion are logical and would be expected in exercise of this intensity and duration. In light of the purpose of this investigation, significant differences would need to be observed between treatments for these finding to be important. This was not the case.

It is possible that more significant findings would have been produced had the caloric value of the placebo foodbar been less. The purpose of this investigation was not to confirm that liquid CHO was better than a placebo. Instead, a foodbar placebo was prepared to examine the effects foodbars had on performance relative to beverages. Unfortunately, the foodbar placebo contained a fairly high caloric content. If a calorie free placebo had been used the benefits of solid and liquid feedings during exercise could have been better evaluated based on the different responses of those exercising under each protocol. Once again, however, it appears that once an adequate level of CHO ingestion is attained any further kcal intake may be superfluous. Accordingly, the four conditions, including the placebo, examined in the present study may each have supplied adequate energy to cause no differential effect upon the measured variables.

In conclusion, it appears that carbohydrate foodbar ingestion during exercise may be equally beneficial as ingestion of a carbohydrate beverage to maintain exercise performance. The limitations imposed on this study by the caloric content of the placebo bar and the relatively small sample obscure more definite remarks regarding differences between treatments.

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Appendix A

Appendices for Research Proposal

Carbohydrate Ingestion and

Performance During Prolonged

Endurance Exercise

Appendix A-1

Informed Consent

1. PURPOSE:
This investigation is being conducted in order to investigate the effects consuming carbohydrates during exercise has on performance.

2. BENEFITS:
Individuals electing to participate will be offered physiological measurements as well as explanations of the measurements and how to utilize them to enhance training and performance. T-shirts will also be awarded to those subjects completing the study.

The information collected in this study will add insight into the subject of carbohydrate feeding during exercise.

3. WHAT WILL BE ASKED OF YOU:
As participants you will be asked to spend a total of 16 hours in the lab. You will first be asked to complete an exercise test on an indoor bike to obtain baseline information. Your task will then involve riding an indoor cycle while ingesting a carbohydrate source at regula intervals. Physiological parameters will be measured at 20 minute intervals throughout the rides. Some of these measurements require the temporary use of a mouth piece. Blood samples will be drawn from your non-dominant hand before exercise onset and at 20 minute intervals throughout the ride. Your diet and activity will be controlled beginning 3 days prior to each ride.

Initial___________Cont.

Appendix A-1 (Cont.)

This will involve following a high carbohydrate diet and your normal exercise regime. You will be asked to refrain from caloric intake 12 hours before exercise onset.

The cycles used during the test rides will be equipped with a rack to permit reading. Television will also be available during the exercise. To ensure proper fluid intake and promote a proper exercise environment fluid will always be available and a fan will be used to circulate air during the rides.

4. RISKS:
As a result of the riding duration participants may experience muscle soreness. This soreness is temporary and typically will subside in 2-3 days.

The possibility of infection is also present since blood will be drawn. Sterile lancets will be used as well as sterile gloves at all times to minimize this risk.

The possibility of injury is inherent in any form of exercise. As health care professionals in the field of sports medicine we have taken every precaution to ensure the safety of the participants. We are also trained to safely deal with any situations that may arise. The Hammond Health Center will be available for physician referral should these services be required during testing or evaluation.

5. WITHDRAW FROM THE STUDY:
You are free to withdraw from the study at any time, for any reason, without penalty or questioning.

Initial___________Cont.

Appendix A-1 (Cont.)

6. CONFIDENTIALITY
All data collected in this study will be held in complete confidence. Your data will always be presented in such a way that your name will not be associated with your data.

7. QUESTIONS, COMMENTS, CONCERNS?
If any questions should arise before, during, or after the study, feel free to contact:

Mike Cendoma
Certified Athletic Trainer
125 Cambell Ave
Ithaca, NY 14850
(607)277-4479

Dr. Gary Sforzo
Room 27 Hill Center
Ithaca College
Ithaca, NY 14850
(607)274-3359

Signature:________________________ Date____________

Appendix A-2

Medical History/Health History Questionnaire

Name________________________ AGE________ Bday____________

Work
Address______________________ Phone_________________

Home
Address______________________ Phone_________________

Physician________________________ Phone_________________

FAMILY HISTORY- Check if any blood relatives (parents, sister, siblings, etc.) had?

Heart Disease () Stroke() Diabetes()
High Blood Pressure () High Cholesterol()

Other conditions/comments:

MEDICAL/HEALTH HISTORY- Check if you ever had?

Heart Disease/Stroke	()	Lung Disease	()
High Blood Pressure	()	Diabetes	()
Heart Murmur	()	High Cholesterol	()
Skipped, rapid beats, or irregular rhythms	()	Epilepsy	()
Rheumatic Fever	()	Injuries to back, knees, or ankles	()

Other conditions/comments:

Initial___________Cont.

Appendix A-2 (Cont.)

PRESENT SYMPTOMS-Have you recently had?

Chest Pain	()	Illness, surgery, or hospitalization	()
Shortness of Breath	()	Ankle/leg swelling	()
Lightheadedness	()	Joint/Muscle Pain	()
Heart Palpitations	()	Allergies	()
Loss Of Consciousness	()		

Other conditions/comments:

LIST ALL MEDICATIONS PRESENTLY TAKING

____

____

____

HEALTH HABITS

1. SMOKING HISTORY
   Do you smoke? ()yes ()Quit ()Never
   What do(did) you smoke? ()Cigarettes ()Cigars ()Pipe
   How Much do(did) you smoke a day?____________
   How long have(had) you been smoking?__________
   If quit, when?____________________

2. EXERCISE HABITS
   Do you presently engage in physical activity?()yes()no
   What kind?______________________________
   How hard? ()Light ()Moderate ()Hard
   How Often?______________________________

Initial__________Cont.

Appendix A-2 (Cont.)

Did your past exercise habits differ from what you are doing now? ()yes ()no

What kind of exercise did you do in the past?

____

How hard? ()Light ()Moderate ()Hard

How Often?____________________________________

Is your occupation- ()sedentary, ()active, ()heavy work
Explain your occupation:_______________________

3. NUTRITIONAL BEHAVIOR
How many meals do you typically eat per day?___________
How often do you eat outside of the home?________/wk

Do you presently consume alcohol? ()yes ()no
If yes, what?_______________,#/week____

4. STRESS
Do you consider your day stressful? ()yes ()no
What is the nature of your stress?_____________________
How many hours do you sleep a night?___________________
Is your sleep sound ()yes ()no

ADDITIONAL PERTINENT INFORMATION:

Signature____________________________________Date_______

Appendix A-3

24 Hour History

NAME:______________________ DATE:________________ TIME:_______

How many hours of sleep did you get last night?
(circle one) 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

How many hours of sleep do you normally get?
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

How long has it been since your last meal or snack?
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

List the items eaten below:

____

When did you last:
- Have a cup of coffee or tea________________________
- Smoke a cigarette, cigar, or pipe__________________
- Take drugs(including aspirin)______________________
- Drink alcohol______________________________________
- Give blood____
- Have an illness_____________________________________
- Suffer from a respiratory problem__________________

What sort of physical exercise did you perform yesterday?

What sort of exercise did you perform today?

Initial____________Cont.

Appendix A-3 (Cont.)

Describe you general feelings by checking on of the following:

Excellent____ Very, very good ____ Very good____
Terrible ____ Very, very bad ____ Very bad ____
Bad ____ Neither good or bad ____

Signature____________________ Date______________

Appendix A-4

Pre-Exercise Test Instructions

Test Date_______ Test Time________

Call 277-4479 if you have any questions or if you are unable to make this time.

You are scheduled to complete a 3 hour test ride on the date and time given above. Your test performance depends on adherence to the following instructions. Some suggestions may also make the test more comfortable.

1. Do not perform heavy exercise in the 24 hours prior to the test.
2. Do not drink alcohol for 12 hours prior to the test.
3. Do not use caffeine (e.g., coffee, soda) or nicotine (e.g., cigarettes, chew) 3 hour prior to the test.
4. Do not eat 8 hours prior to the test.
5. Maintain a diet of which 70% of your calories come from carbohydrates.
6. Do not eat any food that may cause you discomfort the day of the test.
7. Avoid over-the-counter medications 12 hours prior to the test. However, cancel the appointment if you are feeling ill and treat yourself accordingly.
8. Bring your pedals and shoes and any other riding gear you feel will make you more comfortable.
9. An extra shirt is advised as you will sweat heavily in the later stages of the test.
10. Let me know of any movie or music requests you are interested in 2 days prior to the test.
11. It takes approximately 2 hour to prepare the lab for each test so please contact me the day before the test if you are unable to make your appointment.

Appendix A-5

RPE Scale

6	
7	Very, Very Light
8	
9	Very Light
10	
11	Fairly Light
12	
13	Somewhat Hard
14	
15	Hard
16	
17	Very Hard
18	
19	Very, Very Hard
20	

Tables and Figures for Research Manuscript

Carbohydrate Ingestion and Performance During Prolonged Endurance Exercise

Appendix B-1

Table 1

General Linear Models Procedure
Repeated Measures Analysis of Variance
Univariate Tests of Hypotheses for Within Subjects Effects For Lactates

Source (df)	**SS**	**MS**	**F**	**p**
Interaction (3)	171411.8	57137.3	0.25	0.8565
Time Main Effect (3)	99485.0	3161.6	2.24	0.1008
Treatment Main Effect (9)	124932.2	13881.3	0.94	0.5069
Error (36)	534064.3	14835.1		

Appendix B-1 Cont.

Table 2

General Linear Models Procedure
Repeated Measures Analysis of Variance
Univariate Tests of Hypotheses for Within Subjects
Effects For Glucose

Source (df)	**SS**	**MS**	**F**	**p**
Interaction (3)	3187.2	1062.4	0.44	0.7315
Time Main Effect (3)	1642.2	547.4	1.35	0.2734
Treatment Main Effect (9)	2383.8	264.8	0.65	0.7441
Error (36)	14591.2	405.3		

Appendix B-1 Cont.

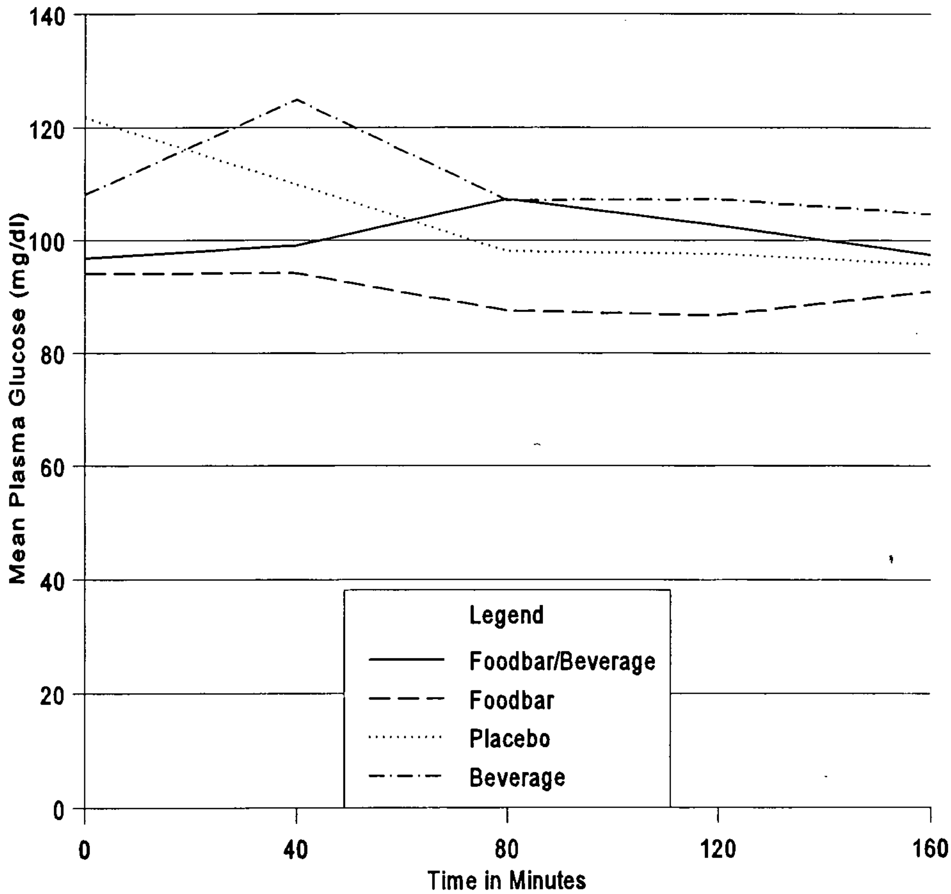

Figure 1. Mean glucose levels as a product of time.

Appendix B-2

Table 1

General Linear Models Procedure
Repeated Measures Analysis of Variance
Univariate Tests of Hypotheses for Within Subjects
Effects For Work Capability

Source (df)	**SS**	**MS**	**F**	**p**
Interaction (3)	1607.9	535.9	0.16	0.9227
Time Main Effect (3)	2073.7	691.2	12.99	0.0001
Treatment Main Effect (9)	473.2	52.5	0.99	0.4624
Error (48)	2555.1	53.2		

Appendix B-2 Cont.

Table 2a

Post-hoc Paired t-test With a Bonferoni Adjusted Alpha of $p < 0.01$ to Examine Mean Differences in Work Capability Between Time = 0 min and All Other Time Intervals.

Time in min vs T = 0	**Mean Diff.**	**DF**	**t-Value**	**P-Value**
40	7.100	19	1.690	0.1073
80	13.000	19	2.668	0.0152
120	15.950	19	3.146	0.0053
160	21.150	19	3.555	0.0021

Appendix B-2 Cont.

Table 2b

Post-hoc Paired t-test With a Bonferoni Adjusted Alpha of $p < 0.01$ to Examine Mean Differences in Work Capability (WC) Between Time(T) = 120 min and Time(T) = 160 min of Exercise.

$WC_{120\ min}$ vs $WC_{160\ min}$

Mean Difference	**DF**	**t-Value**	**P-Value**
5.200	19	2.417	0.0259

Appendix B-3

Table 1

General Linear Models Procedure
Repeated Measures Analysis of Variance
Univariate Tests of Hypotheses for Within Subjects Effects For Heart Rate

Source (df)	SS	MS	F	p
Interaction (3)	505.3	168.4	0.16	0.9199
Time Main Effect (3)	14.1	4.7	0.20	0.7274
Treatment Main Effect (9)	146.3	16.2	0.67	0.7274
Error (48)	1156.3	24.0		

Appendix B-4

Table 1

General Linear Models Procedure
Repeated Measures Analysis of Variance
Univariate Tests of Hypotheses for Within Subjects
Effects For Perceived Exertion

Source (df)	**SS**	**MS**	**F**	**p**
Interaction (3)	3.1	1.0	0.18	0.9104
Time Main Effect (3)	138.7	46.2	34.74	0.0001
Treatment Main Effect (9)	12.6	1.4	1.05	0.4140
Error (48)	63.9	1.3		

Appendix B-4 Cont.

Table 2a

Post-hoc Paired t-test With a Bonferoni Adjusted Alpha of $p < 0.01$ to Examine Mean Differences in Perceived Exertion Between Time(T) = 40 min and All Other Time Intervals.

Time vs T = 40 min	**Mean Diff.**	**DF**	**t-Value**	**P-Value**
80 min	-1.600	19	-4.465	0.003
120 min	-2.550	19	-5.667	< 0.0001
160 min	-3.750	19	-6.795	< 0.0001

Appendix B-4 Cont.

Table 2b

Post-hoc Paired t-test With a Bonferoni Adjusted Alpha of $p < 0.01$ to Examine Mean Differences in Perceived Exertion(PE) Between Time(T) = 120 min and Time(T) = 160 min of Exercise.

$PE_{120\ min}$ vs $PE_{160\ min}$

Mean Difference	**DF**	**t-Value**	**P-Value**
-1.200	19	-5.339	< 0.0001

Appendix B-5

Table 1

General Linear Models Procedure
Repeated Measures Analysis of Variance
Univariate Tests of Hypotheses for Within Subjects Effects For Oxygen Consumption

Source (df)	**SS**	**MS**	**F**	**p**
Interaction (3)	76.6	25.5	0.11	0.9515
Time Main Effect (3)	38.6	12.8	1.43	0.2508
Treatment Main Effect (9)	49.0	5.4	0.60	0.7857
Error (36)	324.9	9.0		

Appendix B-5 Cont.

Table 2

General Linear Models Procedure
Repeated Measures Analysis of Variance
Univariate Tests of Hypotheses for Within Subjects Effects For Respiratory Exchange

Source (df)	**SS**	**MS**	**F**	**p**
Interaction (3)	0.4	0.1	2.25	0.1349
Time Main Effect (3)	0.0	0.0	1.68	0.1891
Treatment Main Effect (9)	0.0	0.0	0.78	0.6320
Error (48)	0.1	0.0		