THE EFFECT OF PRE-EXERCISE GLUCOSE INGESTION ON PERFORMANCE DURING
PROLONGED SWIMMING

by

GARETH JAMES SMITH

B.Sc H.K., University of Ottawa, 1996.

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR

THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

SCHOOL OF HUMAN KINETICS

We accept this thesis as conforming to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

APRIL 2000

© Gareth James Smith, 2000

In presenting this thesis in partial fulfilment of the requirements for an advanced degree at the University of British Columbia, I agree that the Library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the head of my department or by his or her representatives. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Department of Human Kinetics.

The University of British Columbia
Vancouver, Canada

Date Apr. 1 26/2000.

ABSTRACT

The purpose of this study was to determine if pre-exercise glucose ingestion would improve 4000m swimming performance. Additionally, glucose was provided at two different feeding intervals to determine the influence of timing. Ten male triathletes ($\bar{X} \pm \text{SD}$: age 29.5 ± 5.0 , $\text{V}_{\text{O}_2\text{max}} 3.74 \pm 0.10 \text{ L} \cdot \text{min}^{-1}$) swam 4000m on three occasions following the consumption of either: 1. a 10% glucose solution 5-min prior to exercise (G^5), 2. a 10% glucose solution 30-min prior to exercise (G^{35}), 3. a similar volume of placebo (PL). Dietary intake and exercise were regulated for 48 hours prior to each trial. Despite a significant difference ($p < 0.001$) in blood glucose concentration prior to exercise ($\bar{X} \pm \text{SD}$ in $\text{mmol} \cdot \text{L}^{-1}$: $\text{G}^{35} 8.4 \pm 1.1$, $\text{G}^5 5.2 \pm 0.5$, PL 5.3 ± 0.4), no significant differences were observed in total time ($\bar{X} \pm \text{SD}$ in minutes: $\text{G}^{35} 70.7 \pm 7.6$, $\text{G}^5 70.1 \pm 7.6$, PL 71.9 ± 8.4 min), post-exercise blood glucose ($\bar{X} \pm \text{SD}$ in $\text{mmol} \cdot \text{L}^{-1}$: $\text{G}^{35} 5.1 \pm 1.1$, $\text{G}^5 5.1 \pm 0.9$, PL 5.3 ± 0.4), and average heart rate ($\bar{X} \pm \text{SD}$ in bpm: $\text{G}^{35} 155.8 \pm 10.8$, $\text{G}^5 153.6 \pm 12.6$, PL 152.0 ± 12.5) ($p > 0.05$). The results of this study indicate that despite a greater reliance on carbohydrate with this mode of exercise, there was no significant improvement in performance following glucose ingestion. The data further indicates that no decrements to performance were observed following the ingestion of a high glycemic solution thirty-five minutes prior to exercise, despite significant differences in blood glucose between trials immediately prior to exercise.

TABLE OF CONTENTS

Abstract.....	ii
Table of Contents.....	iii
List of Tables.....	v
List of Figures.....	vi
Introduction.....	1
Statement of the problem	2
Secondary problems	3
Rationale	3
Hypotheses	3
Assumptions	4
Limitations	4
Significance	4
Review of related literature.....	5
Methodology.....	23
Experimental Design	23
Subjects	23
Preliminary testing	24
Body fat determination	24
Tethered Swimming V02 max	25
Subject Guidelines	26
Testing Protocol	26
Data Analysis	28
Results.....	30
Subject Characteristics	30
Performance Time	30
Blood Glucose	32
Blood Lactate	33
Heart Rate	34
Rating of Perceived Exertion	34
Dietary Records	34

Discussion.....	36
Overview	36
Exercise Mode	37
Glucose ingestion 35-min prior to exercise	38
Glucose ingestion 5-min prior to exercise	40
Glucose versus Placebo	43
Summary	47
References.....	49
Appendix.....	54

List of Tables

1. Table 1. Fluid content of each of the trials	28
2. Table 2. Subject Characteristics	30
3. Table 3. Individual performance times	31
4. Table 4. Mean heart rate for each trial condition	34
5. Table 5. Mean dietary intake prior to each trial	35
6. Table 6. Individual post-exercise blood lactate	55
7. Table 7. Individual blood glucose measurements (pre and post exercise)	56
8. Table 8. Average heart rate for each subject.	57
9. Table 9. Individual rating of perceived exertion for each trial condition	58
10. Table 10. Individual diet composition prior to each trial	59

List of Figures

1. Figure 1. Mean spilt times for each 1000m.	32
2. Figure 2. Mean blood glucose for each trial	33
3. Figure 3. Performance time differences between glucose and placebo	60

1.0 Introduction

The use of carbohydrates in the context of performance improvement is one of the most studied areas in sports nutrition. Previous studies have clearly demonstrated an enhancement in performance in long duration exercise (over two hours) with carbohydrate supplementation (Costill and Hargreaves, 1992). The rationale is based on the idea that consuming carbohydrates will result in a increase in carbohydrate oxidation and a sparing of both liver and muscle glycogen (Coggan and Coyle, 1988). Performance improvement in events over two hours has been observed both when carbohydrates are consumed prior to or during exercise. Most studies in this area have used exercise protocols that are of this duration or longer, believing that it is necessary to see a decrease in muscle and liver glycogen. Recent research suggests that significant reductions in muscle glycogen may also occur following shorter and more intense exercise, leading to interest in the effect of carbohydrate supplementation in endurance exercise that is close to 60 minutes in duration at an exercise intensity between 75-85%VO₂max. Although the number of studies are small, early results have generally shown endurance performance of this duration can also be improved with carbohydrate supplementation (Jeukendrup et al., 1997; Anantaraman et al., 1995; Neufer et al., 1987). One of the problems in comparing these studies however is that they have little consistency with regard to the timing of the carbohydrate feedings, the dietary restrictions placed on the subjects, and the type of exercise protocol. Sports nutrition research has demonstrated that decrements in performance over shorter duration exercise occur when glucose is ingested within the hour prior to exercise (Foster et al., 1979; Costill et al., 1977). It has previously been speculated that such differences are due mainly to changes in glucose and insulin. The result is that many athletes often ingest carbohydrates immediately prior to or during exercise to avoid any fluctuations in insulin and glucose. Although this strategy has proven to be effective in minimizing metabolic changes, it has yet to be determined if the timing of carbohydrate ingestion affects performance during exercise at this duration and intensity.

The intake of carbohydrates prior to exercise lasting one hour in duration has received little attention in sport nutrition. As such, there are a number of questions that need to be resolved. The first question is whether or not pre-exercise carbohydrate ingestion has any benefit to exercise of this duration. Unfortunately, the small number of studies examining this area have used differing protocols with conflicting results. The protocol in the majority of these studies has been to ingest carbohydrates either immediately prior to or during exercise. A secondary question arises from the finding that certain metabolic differences occur depending on the timing of the feeding (Hargreaves et al., 1987). Whether or not there is any benefit in avoiding the hyperinsulemic response, normally seen with carbohydrate ingestion 30-60 minutes prior to exercise, remains to be determined at this exercise duration. The third question of interest is related to the type of exercise that is employed. Previous research in this area has used either cycling or running as the mode of exercise. Many of these protocols have also incorporated the ingestion of carbohydrates during exercise in addition to pre-exercise feeding, a practice not well suited to swimming. It has also been demonstrated that there are certain metabolic differences between arm and leg exercise. These include; a higher rate of carbohydrate oxidation, a higher release of lactate from the exercising muscle and a higher respiratory exchange ratio (Lavoie 1982; Ahlborg & Jensen-Urstad 1991). These differences would seem to indicate that a greater dependence on carbohydrates may exist during predominantly arm exercise such as swimming.

1.1 Statement of the Problem

The primary purpose of this study was to determine if pre-exercise carbohydrate ingestion would improve the time required to swim a 4000 metre distance.

1.1.2 Secondary Problems

1. To determine if performance is affected by the timing of the carbohydrate feeding.
2. To determine if there is a significant difference in post-exercise blood glucose between trials.

1.2 Rationale

Only a small number of studies have examined the effect of pre-exercise carbohydrate intake on exercise performance of one hour duration, and all of these studies have also been conducted on cyclists. There is a higher rate of carbohydrate oxidation during swimming versus cycling (Lavoie 1982) that is independent of training status (Ahlborg and Jensen-Urstad, 1991). This increased reliance on carbohydrate sources during swimming may be greatly affected by the pre-exercise carbohydrate ingestion. Additionally, the timing of the pre-exercise feedings may have an impact on the performance since it has been demonstrated that differences in metabolism occur as a result of how close the feeding is to the start of exercise. There is little information available as to whether this will affect the actual performance at this duration and intensity.

1.3 Hypotheses

1. Swimming time will be significantly decreased following both carbohydrate trials. Furthermore, ingesting carbohydrate immediately prior to exercise will result in a greater improvement in swimming time when compared to carbohydrate consumed 35 minutes prior to exercise (G³⁵).
2. Post-exercise blood glucose levels will be higher in the trial in which carbohydrates were consumed 5-minutes prior to exercise versus the trial in which carbohydrates were consumed 35 minutes prior to exercise.

1.4 Assumptions

1. Subjects will provide a consistent maximal effort on all trials.
2. Subjects will report to each testing session with the same level of endogenous glycogen.
3. Subjects will follow exercise and dietary guidelines.
4. The temperature of the pool will remain similar between trials.

1.5 Limitations

1. An inability to collect blood glucose and expired gas samples during the performance trials.
2. Inability to extrapolate results to groups other than the subject population (eg. women).

1.6 Significance of the Study

If an improvement in swim performance is observed with the ingestion of carbohydrates then the results may shed some light on an area that has received little attention. In swimming, like most athletic events, success is often determined by a small margin of difference between competitors. A proper fuel replacement strategy has often been a method of improving performance. The integration of both the proper type and timing of feedings is an important component of this strategy for success. Results of this study would be beneficial in informing athletes who compete at this duration and intensity as to the benefits of carbohydrate ingestion. It would also provide practical guidelines as to the correct timing of such feedings. Additionally, results of the study could also provide general guidelines to other sports and activities of similar duration and intensity, as well as those that are unable to ingest carbohydrates during exercise.

Review of Related Literature

The manipulation of fuels in an effort to improve athletic performance has always been an area of considerable interest in sports nutrition. By far one of the most studied areas in the last twenty years has been the use of carbohydrates in a variety of athletic settings. The human body's reliance on endogenous carbohydrate sources during both anaerobic and aerobic exercise is well-established (Hargreaves et al., 1995). The storage form of carbohydrate within the human body is glycogen, the two main sites for this being muscle and liver stores, with a circulating source in the form of blood glucose. Blood glucose sources can be derived from liver glycogenolysis and gluconeogenesis of precursors such as amino acids and lactate. During sustained endurance exercise, muscle glycogen and blood glucose are the main sources of carbohydrate for contracting skeletal muscle. In the absence of exogenous sources, blood glucose is supplied from either liver glycogenolysis or gluconeogenesis (Ball et al., 1995). During sustained moderate to high intensity exercise, both liver and muscle glycogen stores decrease as exercise progresses. As muscle glycogen levels decrease, there is an increased reliance on blood glucose uptake and oxidation, in order to match the energy demands of muscular contraction (Coggan and Coyle, 1991). The importance of carbohydrate availability during endurance exercise has been demonstrated in situations where fatigue has coincided with either hypoglycemia or muscle glycogen depletion (Coggan and Coyle, 1991). However, a supply of exogenous carbohydrate prior to exhaustion will result in either a reversal of fatigue or an increase in exercise duration (Coggan and Coyle, 1988). In light of these findings a number of nutritional strategies have been developed in order to maximize endogenous glycogen stores and/or maintain euglycemia during exercise. The focus of many of these strategies has been to alter either the timing or the composition of the carbohydrate ingested.

Pre-exercise carbohydrate ingestion

One area to have received a great deal of attention in carbohydrate replacement research is the addition of these fuels prior to exercise. The ingestion of carbohydrates during this period

are generally categorized according to when they are consumed, these include: an increase in carbohydrates in the days leading up to exercise, in the hours preceding exercise and within the hour before exercise. The goal of the first two methods is to increase endogenous glycogen stores in the muscle and liver, with the contribution to each related to the timing. Glycogen loading or an increase in carbohydrate in the days before exercise will result in a large increase in muscle glycogen (Hargreaves et al., 1997). Consuming carbohydrates in the hours prior to exercise will elevate hepatic glycogen, which is generally low following an overnight fast (Nillson, 1973), and to a lesser degree muscle glycogen. Both of these approaches have proven to be effective in prolonging exercise of long duration (Costill and Hargreaves, 1992), either by sparing muscle and liver glycogen or by providing a continuous supply of glucose from the gastrointestinal tract.

In contrast, the manipulation of carbohydrate intake within the hour prior to exercise has been less conclusive. One of the first investigators to test the effects of pre-exercise glucose ingestion on exercise performance was Foster et al.(1979). Compared with a placebo, the ingestion of 75g of glucose 30 minutes prior to cycling exercise resulted in; a drop in blood glucose at the beginning of exercise, a decrease in the concentration of free fatty acids, and a 19% drop in performance during the 30min cycling trial (Foster et al., 1979). The investigators attributed the impairment in performance to an increased utilization of muscle glycogen, although this measure was not directly tested. This conclusion was based on an earlier study by Costill et al. (1977) which examined the effects of hyperinsulemia on muscle glycogenolysis during exercise. Under two metabolic conditions, Costill et al. (1977) compared the effects of hyperinsulemia with elevated levels of free fatty acids on muscle glycogen utilization during exercise. The results indicated that an artificial increase in free fatty acid concentration by heparin infusion decreased muscle glycogenolysis, thus promoting a sparing of muscle glycogen. On the other hand, consuming 75 grams of glucose 45 minutes prior to exercise resulted in hyperinsulemia, a decrease in blood glucose at the onset of exercise, and an increased rate of glycogen utilization within the exercising muscle. The investigators attributed the increased rate

of muscle glycogenolysis to the combination of free fatty acid suppression by insulin and a decreased availability of blood glucose as a result of the insulin rebound (Costill et al., 1977).

The result of the aforementioned studies was that any benefit of consuming carbohydrate rich foods in the hour preceding exercise became unclear. The underlying theory for such caution was related to the metabolic changes that occurred following glucose intake. Such changes have included a sharp increase in blood glucose and insulin, and a decrease in free fatty acid mobilization mediated by insulin (Hargreaves et al., 1995). If exercise begins during this period, the combined effects of insulin and muscle contraction mediated glucose uptake will result in what has been termed transient hypoglycaemia (Foster et al., 1979; Coggan and Coggan, 1991). The reason for using such a definition is that it is not indicative of total depletion in glycogen stores and persists only until glucose output from the liver equals the demand from skeletal muscle (Short et al., 1997). The effect that these metabolic disturbances have on performance is not well understood and has been suggested to be variable between subjects. While some individuals may experience drops in blood glucose that may be severe enough to affect performance (Coggan and Coyle, 1991, Foster et al., 1979), the decrease may be either too brief or too small to affect most people (Coggan and Coyle, 1991). This drop in blood glucose is eventually counterbalanced by an increase in hepatic glucose output, and a catecholamine mediated suppression of insulin at the level of the pancreas. This however is assuming that the exercise is done at an intense enough level to cause a significant rise in catecholamines (Marker et al., 1991). Strategies to avoid transient hypoglycaemia have included ingesting carbohydrates with differing glycemic indexes, which do not produce such a large increase in blood glucose and insulin, or timing the feeding so that it is done immediately prior to exercise. Adjusting the timing in this way will result in a dampened rise in insulin at the onset of exercise, due to its suppression by circulating catecholamines. The effect of altering the feeding times of high glycemic beverages in such a way has not been well studied.

Another of the early concerns regarding pre-exercise carbohydrate ingestion was the belief that it would cause an increase in muscle glycogen utilization as a result of hyperinsulemia. An elevated insulin concentration has previously been shown to increase phosphofructokinase activity and glycogenolysis. Since muscle glycogen content prior to exercise has been shown to be a major determinant of endurance capacity (Hargreaves et al., 1985), there was concern that performance would be decreased if there was an accelerated utilisation of muscle glycogen in the early stages of exercise. Although earlier results of Costill et al (1977), showing an increase in muscle glycogenolysis, have been supported by Hargreaves et al (1985), there have been other studies that have failed to show an increase in muscle glycogenolysis following glucose ingestion (Devlin et al.1986; Hargreaves et al 1987; Koivisto et al. 1985). There is however a difference in the length and intensity of exercise between these conflicting studies. Those that have shown an increased rate of glycogenolysis have typically used a higher intensity protocol lasting approximately 30 minutes (Costill et al., 1977; Hargreaves et al., 1985). Conversely, longer exercise trials lasting over 2 hours generally show no change in muscle glycogen utilisation during exercise following a pre-exercise feeding (Devlin et al.,1986; Hargreaves et al., 1987; Koivisto et al.,1985). This may be a direct result of the exercise intensity.

Although there is a direct relationship between muscle glycogen utilization and exercise intensity, it remains to be determined if such a relationship can be altered by the ingestion of glucose prior to exercise. Although it does appear that metabolic changes do occur following pre-exercise carbohydrate ingestion, it does not appear likely that such changes will have a detrimental effect on endurance exercise lasting greater than 90 minutes (Sherman et al., 1991). In a review article summarising a number of investigations in which carbohydrates were consumed 30-60 minutes prior to exercise, Hawley and Burke (1997) concluded that only one article out of eleven demonstrated a decrease in performance during the carbohydrate trial. The remaining studies showed either an improvement or no change versus the placebo. The reason

for such differences between studies is most likely the result of individual metabolic changes, the training status of the subjects, and the testing protocols that were employed (Liebman, 1994). In those experiments that have shown an increase in performance over prolonged endurance exercise, the mechanism is believed to be related to greater carbohydrate availability throughout exercise (Coggan and Coyle, 1991, Sasaki et al., 1987). This occurs as a result of a slow release of carbohydrate from the gastrointestinal tract during exercise, as well as a sparing of hepatic glycogen (Liebman, 1994, Marmy-Conus et al., 1996). A significant reduction in liver glucose output has previously been demonstrated during exercise following pre-exercise carbohydrate ingestion (Marmy-Conus et al., 1996). The preservation of hepatic glycogen stores would be advantageous in the later stages of exercise when blood glucose is oxidised at a higher rate and a supply would be readily available (Coggan and Coyle, 1988).

Most studies that have demonstrated an improvement in performance following carbohydrate ingestion have used exercise protocols that are longer than ninety minutes in duration. In contrast, investigations utilising a shorter and more intense exercise trial have not been extensively studied. Since muscle glycogen utilisation is directly related to exercise intensity, it has been hypothesised that during high intensity exercise a decrease in muscle glycogen may result in a drop in performance. If a source of carbohydrates is ingested prior to glycogen depletion, an increase in exogenous carbohydrate oxidation may help maintain performance. Presently however, research under a variety of circumstances has failed to support such a theory (Hargreaves et al. 1985; Palmer et al. 1998; Snyder et al. 1993; Wouassi et al. 1997). The reasons for this have generally been attributed to the high intensity nature of the exercise protocol. Although a significant decrease in muscle glycogen has been observed following brief high intensity exercise (Shephard and Leatt, 1987), the time period during the trials may not have been long enough to deplete glycogen, or other factors may have contributed more to fatigue. Additionally, the intensity of exercise may have slowed the emptying of fluid from the stomach. It has previously been observed that when endurance exercise exceeds

75%VO₂max, there will be a significant reduction in gastric emptying (Gisolfi and Duchman, 1992). Whatever the limitation, current evidence strongly suggests that no benefit is gained by ingesting carbohydrates prior to exercise lasting thirty minutes or less.

Endurance Exercise Lasting One Hour

It has previously been shown that carbohydrate ingestion will generally improve exercise performance greater than two hours but is less likely to benefit intense exercise of less than thirty minutes. This has led to interest in carbohydrate ingestion with exercise durations that are shorter (45 and 75 minutes) and more intense (80-90%VO₂max) than those observed with prolonged endurance exercise. The rationale is that although sixty minutes of exercise may not be long enough to deplete glycogen at a moderate intensity (50-70%VO₂max), if it exceeded 80% of VO₂ max, it may be intense enough and long enough to cause a decrease in endogenous glycogen. If a suitable exogenous source is not available during this period, there may be a limitation on the ability to sustain high intensity exercise. One of the first investigations to research this area was conducted by Neuffer et al.(1987) and involved the consumption of either 45g of liquid or solid carbohydrate five minutes prior to the start of a 45 minute cycle at 77%VO₂max. This was subsequently followed by a 15-minute performance ride at a self-selected pace. The subjects demonstrated a significantly greater total work output during the performance ride following carbohydrate ingestion. The increase in work performed was highest during the final minutes of exercise. A further increase in total work was observed when an additional meal was consumed 4 hours prior to the start of exercise, despite similar levels of muscle glycogen between all trials. This finding suggests that although endogenous glycogen levels may be normal following the ingestion of the test meal, an additional supply of carbohydrate immediately prior to exercise was able to further enhance performance. It would have been interesting for the investigators to include an additional trial in which only a test meal was given, without the inclusion of the pre-exercise carbohydrate. This may have clarified if the

performance originally seen with the test meal and pre-exercise carbohydrate was the result of the test meal alone, and whether any additional carbohydrate consumed after this point would have provided any further increase in performance. This would have indicated that a dose response relationship does not exist with the amount of carbohydrate ingested and performance at this intensity and duration. The investigators speculated that the improvement in performance may have been due to an increased utilization of exogenous carbohydrate and a decreased reliance on hepatic glycogen (Neufer et al., 1987). In an effort to confirm some of these earlier findings Anantaraman et al. (1995) investigated the effect of carbohydrate intake prior to 1 hour of high intensity exercise. Using a cycling protocol, subjects started at a power output that corresponded to 90% of their VO_2 max and attempted to maintain this intensity for the duration of a 60-minute trial. Compared with the placebo, ingesting the carbohydrate solution immediately prior to exercise resulted in the ability to maintain a higher power output during the course of the sixty-minute exercise period. A third trial, which utilized an additional carbohydrate feeding during exercise, resulted in a similar performance as the pre-exercise only feedings. The investigators attributed the inability to further enhance performance to either a decrease in the rate of gastric emptying or a plateau in the amount of carbohydrate that can be utilised. A decrease in gastric emptying has been observed during exercise that exceeds an intensity of 80% VO_2 max (Gisolfi and Duchman, 1992). In an attempt to confirm these earlier findings, Jeukendrup et al. (1997) investigated the effects of pre-exercise carbohydrate ingestion during an exercise session that was set out to mimic a cycling time trial. The subjects were instructed to complete a standardised amount of work on a cycle ergometer in the fastest amount of time possible. This method has previously been shown to be more reliable between tests (Jeukendrup et al., 1996). During the experimental trial the subjects were provided with a carbohydrate beverage both immediately prior to and during the approximately 60 minutes of exercise at an intensity close to 85% VO_2 max. The results indicated that the subjects were able to increase their average workload and decrease the time required to complete the performance trial

following the ingestion of the carbohydrate beverage. The carbohydrate solution was consumed both immediately prior to and at 3 intervals during the test. Using a similar length of exercise time but with a slightly different protocol, Ball et al.(1995) investigated the effect of carbohydrate replacement during a 50 min of cycling at 80%VO₂ max on the performance of a subsequent anaerobic test. Compared with the placebo, ingesting a 7% carbohydrate electrolyte solution during the 50-minute cycle was effective in increasing the peak power, mean power and minimum power during the 30 second Wingate test that immediately followed. The improvement in performance was speculated to have been the result of a sparing of muscle glycogen by the ingestion of an exogenous source of carbohydrate. This occurred at a time when liver glycogenolysis was reduced due to low levels of glycogen, and gluconeogenesis was decreased due to the high intensity of the exercise (Ball et al, 1995). In a similar study by Below et al. (1995), trained cyclists undertook a 50 min cycle at 80%VO₂max followed by a 10 minute self paced performance test. Improvements in performance were based on the time required to complete an individually determined amount of work. The intention was to mimic the finish at the end of a 40 km time trial. Solutions containing the carbohydrate were consumed only during the initial 50-minute ride. The investigators observed a 6.5% decrease in the time required to complete the 10-minute trial with the ingestion of a carbohydrate beverage. There was an improvement in performance despite no significant increase in carbohydrate oxidation, and only a slight elevation in blood glucose following carbohydrate ingestion. In the only study to utilise running as the mode of exercise Sasaki et al. (1987) tested the effects pre-exercise sucrose ingestion on the length of time subjects could run at a speed corresponding to 80% of their maximal oxygen consumption. The rationale for testing runners was that higher levels of muscle recruitment have been observed in runners compared with cyclists. The results indicated a 47% increase in the time to exhaustion following sucrose ingestion, as well as an increased oxidation of carbohydrates as evidenced by a higher respiratory exchange ratio. Not all studies that have been conducted on moderate duration exercise have found an improvement in performance with

pre-exercise carbohydrate ingestion. Although the research is limited, the differences may be partly explained by dissimilarities in the methodology. Using a high carbohydrate food 30-min prior to the start of exercise, Devlin et al.(1986) tested the effect of a pre-exercise meal on prolonged intermittent cycling lasting approximately 50-minutes in duration. Although there was an increase in time to exhaustion during the carbohydrate trial, it did not reach statistical significance. Additionally there were no differences observed between trials with respect to muscle glycogen, blood lactate, and blood glucose. One noticeable difference of this trial compared with previous studies is the intensity the subjects rode at during the 50-minute cycle, which varied between 68 and 70% of VO₂ max. In previous studies that have used shorter duration activity lasting approximately 60 minutes, the intensity has been greater than 80% VO₂ max. It can be argued that if the intensity of the exercise is not sufficient to cause a decrease in the available fuel, then any exogenous source of carbohydrate will not be needed and therefore will not improve performance. The reason for using a lower intensity in this study may have had to do with the training status of the subjects, who were described as untrained. If the intensity had been set above 80%VO₂ max, it is doubtful that the subjects would have been able to maintain this pace for close to an hour. In a similar study using endurance athletes and implementing a 15 minute performance ride following a 45 minute ride at 67%VO₂ max, Sparks et al.(1998) also observed no improvement in performance with the carbohydrate trial. Again the intensity of the submaximal ride was only reported to be at 67%VO₂ max, which is most likely not intense enough to significantly decrease any endogenous carbohydrate stores, during one hour of exercise. In those investigations that have failed to observe any improvement in performance, they have all used exercise intensities that would probably be considered moderate and sustainable for well over an hour in trained individuals.

It has been suggested that the discrepancy of the results may be due to differences in endogenous glycogen levels between subjects, and that performance is enhanced only in those situations where glycogen levels are less than optimal (Coggan and Coyle, 1991; Neufer et al.,

1987). Since it is known that liver glycogen is reduced following an overnight fast, carbohydrate ingestion prior to exercise may be most beneficial in these circumstances. In the protocol utilised by Neufer et al.(1987), the investigators deliberately decreased endogenous glycogen levels prior to exercise by combining a calorie-reduced diet, an overnight fast and exhaustive exercise on the day prior to the test. Despite an improvement in performance, the investigators could only conclude that carbohydrate intake prior to 1 hour of endurance exercise was beneficial in this situation due to intentionally lowered levels of endogenous glycogen. This has led to questions about the usefulness of such a supplementation strategy in real athletic situations, since more often than not athletes compete with elevated levels of endogenous glycogen. Although subsequent studies have taken measures to ensure a normal concentration of muscle glycogen, a number have used an overnight fast in their protocol. The reason for doing this during experimental trials is to control for fluctuations in liver glycogen, as well as duplicate those situations where athletes compete in an early morning competition. In one such study that utilised an early morning testing protocol, the majority of subjects indicated that they do not often eat before exercising in the morning. An early morning start time does not allow the athlete to ingest foods several hours prior to competing, resulting in a self selected fast (Ball et al. 1995; Hawley et al., 1997). Improvements in exercise performance have not been restricted to those studies which have utilised either a glycogen depletion strategy or an overnight fast. Anantaraman et al. (1995) demonstrated an increase in cycling performance over 60 minutes with the carbohydrate trial, even though subjects reported to the laboratory in a four hour post absorptive state, suggesting that endogenous glycogen levels were close to normal. These results are supported by Jeukendrup et al.(1997) who also demonstrated a performance improvement in the carbohydrate trial despite limiting subject food intake to only the hour prior to exercise. Although both studies requested that the subjects maintain normal dietary patterns during the study and attempt to repeat the same food intake in the day prior to the test (Jeukendrup et al., 1997), dietary intake was not strictly controlled and variations in endogenous glycogen levels

may have occurred. These studies appear to contradict the belief that pre-exercise carbohydrate ingestion is useful only during situations where subjects are fasted and hepatic glycogen stores are less than optimal

Another variable that has often made it difficult to compare studies involves the timing of the carbohydrate feedings. The timing of these feedings can essentially be broken down into two periods; either immediately prior to or 30-60 minutes before exercise. It can be theorised that most studies are using feeding times immediately prior to exercise in order to avoid any possible increase in insulin at the onset of exercise (Neufer et al., 1987). Although the small number of studies makes it difficult to conclude, those studies that have observed a performance enhancement have typically used pre-exercise feedings almost immediately prior to and/or during exercise (Anantaraman et al., 1995; Jeukendrup et al., 1997; Neufer et al., 1987). While those showing no improvements have used a protocol in which feedings occur between 30-60 minutes prior to exercise (Devlin et al 1986., 1986; Sparks et al., 1998). Based on the limited data it is very difficult to speculate if this represents a trend, however it should be noted that no studies that have examined pre-exercise CHO ingestion and one hour of exercise have compared the timing of the pre-exercise meals. It is largely unknown whether the metabolic differences that have been observed with various feeding periods will alter the ability to maintain a high level of performance at this intensity and duration.

Proposed Mechanisms

Although there are only a small number of studies that have investigated pre-exercise CHO intake and exercise lasting 60 minutes, it does appear that a benefit to performance does occur. What is less clear however is the mechanism by which this happens. Previous studies that have examined pre-exercise CHO with respect to long duration exercise have indicated that sparing hepatic glycogen stores, as well as providing a supply of glucose from the gut may enhance performance. It is doubtful that improvement over 60 minutes occurs as a result of this

mechanism. Although it has been shown that there is a higher level of blood glucose at the end of 60 minutes of exercise following the ingestion of carbohydrate (Anantaraman et al., 1995; Below et al., 1995; Neuffer et al., 1987), blood glucose levels of the placebo group are still within what is considered a normal range. Although a difference in blood glucose has been shown to occur between the experimental and control trials, it is unknown if such an elevation is responsible for any benefit in performance. Investigations conducted by Neuffer et al.(1987) and Below et al. (1995) both demonstrated an increase in blood glucose and exercise performance with the carbohydrate trial, however this occurred in the absence of any increase in carbohydrate oxidation. Although the exact mechanism remains unknown, it has been speculated that the improvement may be due to either an increased synthesis of TCA-cycle intermediates (Jeukendrup et al., 1997), which will result in a greater power output, or an increased utilisation of blood glucose in the later stages of exercise when muscle glycogen levels may have become reduced (Anantaraman et al., 1995). These hypotheses are entirely speculative and further research is needed to determine the exact mechanism by which performance is improved. In an effort to determine if performance during 60 minutes of cycling could be improved with elevated muscle glycogen levels, Hawley et al.(1997) intentionally raised muscle glycogen levels for three days leading up to the performance trial. Despite a 23% increase in muscle glycogen there was no difference in the time required to complete the distance between trials.

Mode of exercise

One of the more relevant areas in the context of carbohydrate ingestion involves the metabolic differences that have been observed between arm and leg exercise. In a study comparing metabolic substrates between swimming and leg cycling, Lavoie (1982) observed higher blood lactate and pyruvate concentrations with swimming as compared with cycling at 70% of VO_{2max} . The investigators suggested that these differences were due to a higher relative rate of carbohydrate oxidation with swimming. Although the mechanism for this difference was

not directly determined, it was speculated that the increased oxidation of carbohydrate could be the result of training, or the recruitment of different muscle fibre types. Although there have been on only a small number of studies to compare swimming and cycling, there have been a number that have examined arm and leg exercise. The results of these studies have supported the previous findings of Lavoie (1982), by observing: a higher blood lactate concentration, an increased release of lactate from the exercising muscle, a higher rate of muscle glycogen degradation, an increased blood flow relative to limb volume, and a higher respiratory exchange ratio in arm compared with leg exercise (Ahlborg and Wahren, 1986; Ahlborg and Jensen-Urstad 1991). Previous research involving leg exercise has demonstrated that as there is an increase in the intensity and duration of exercise, there is a substantial rise in the uptake and utilization of blood glucose by exercising muscle. This increase results in both an elevation in the percentage of carbohydrate oxidised and the proportion of blood glucose that contributes to total carbohydrate oxidation (Wahren 1971). However, these percentages are increased further during arm exercise. In a study investigating glucose and lactate metabolism during arm exercise, Ahlborg and Wahren (1986) found a higher fractional utilisation and dependence on blood glucose by the exercising limb during arm versus leg exercise. The data also indicated that between 67-75% of total arm oxidation was accounted for by glucose uptake compared with 43-44% during leg exercise. Since arm exercise has been described as being a more physiologically stressful activity, it has been speculated that the intensity of the contraction may have contributed a large part to the increased utilisation of carbohydrate. This theory however has been deemed unlikely since increasing the intensity of the leg exercise did not result in an increased extraction of blood glucose in the leg (Ahlborg and Wahren, 1986). In a later study designed to quantify the metabolic differences between arm and leg exercise Ahlborg and Jensen-Urstad (1991) observed significant differences in blood glucose and lactate kinetics. As the intensity of arm exercise increased, there was a disproportionate rise in lactate output compared with glucose uptake. An imbalance between glucose uptake and lactate release was suggested to indicate a greater

utilisation of muscle glycogen in the exercising arm muscle. Although the exact mechanisms were not determined, it has been speculated that the difference may be due to differences in training status, circulating levels of epinephrine, or differences in the fibre types between arm and leg muscle. Based on the knowledge that there is an increase in the concentration of oxidative enzymes following aerobic training, it has been speculated that upper body musculature will only display a disproportionate increase in lactate concentration in untrained muscle. To test this hypothesis Ahlborg and Jensen-Urstad (1991) compared the release of muscle lactate in both arm and leg exercise in trained and untrained subjects. The data indicated that the difference between lactate release in the arm and leg muscle was similar between trained and untrained individuals, providing evidence that higher lactate release from the arm muscle cannot be explained by training status. An additional theory was the belief that the metabolic differences between arm and leg exercise could be explained by dissimilarities in hormone levels, specifically epinephrine. Epinephrine is associated with an increase in glycogenolysis and glucose release from the liver. Since higher levels of epinephrine have been observed with arm exercise it has been proposed that this may account for the observed differences. However, based on available research it does not appear that this is a likely explanation, since comparable levels of lactate have been observed with arm exercise with both α -adrenoceptor blockade (Jensen-Urstad et al. 1993) and in an environment of reduced epinephrine concentration (Ahlborg and Jensen-Urstad, 1991). Whatever the mechanism that causes such changes there is strong evidence to suggest that there is an increased reliance on blood glucose and carbohydrate as a whole during arm exercise. As was previously stated, the main source of blood glucose is derived from the liver, bloodstream, and gastrointestinal tract. Therefore, if carbohydrate availability during swimming becomes compromised, an exogenous supply may result in a significant improvement in performance. Most studies that have been conducted in the area of pre-exercise carbohydrate ingestion have used predominantly cycling or running as the mode of exercise. In contrast to the recruitment of predominantly lower body musculature in running and

cycling, swimming relies on a significant amount of upper body musculature. As a result of the added arm component, body position, and hydrostatic pressure of water during swimming, it is difficult to generalise the data obtained during cycling and running to swimming. In addition, no studies that have examined pre-exercise carbohydrate and moderate duration activity have used arm and leg exercise.

Besides any physiological differences that exist between swimming and cycling, one other significant difference involves the feasibility by which fluid can be consumed. During cycling and running an individual can often ingest carbohydrates both prior to and during exercise. Previous studies that have been conducted on cyclists have taken this into consideration, and often provided subjects with CHO in both of these situations. Therefore limiting the number of studies that have used only a pre-exercise feeding. In a sport such as swimming the practicality of ingesting carbohydrates during exercise is limited, allowing only for carbohydrate intake prior to exercise

Type of carbohydrate

Undoubtedly, no one area with regard to carbohydrate beverages has been more researched than the type of carbohydrate consumed. The reason for such interest has typically occurred as a result of the differences that exist between various forms of carbohydrates and the metabolic responses that have been observed. One of the most striking metabolic changes to occur following the ingestion of carbohydrate rich foods are the changes in blood glucose and insulin. In an effort to classify foods based on the blood glucose response following ingestion, the glycemic index was developed. Glucose is classified as having a high glycemic score because it typically results in a sharp increase in blood glucose followed by a pronounced decline due to the effect of elevated levels of insulin. As previously mentioned it was theorized that such changes would cause metabolic disturbances during exercise that may impair performance. These disturbances have been speculated to include; an inhibition of free fatty acid mobilisation,

an increased reliance on muscle glycogen, and hypoglycemia in some susceptible individuals. As a result, alternate forms of carbohydrate have been researched which do not exhibit the same metabolic changes occurring with glucose. These have included alternatives such as sucrose, fructose and maltose. Fructose was first seen as an attractive alternative to glucose because of a smaller rise in blood glucose and insulin. It was theorized that this would provide a more sustained release of carbohydrate and would provide fuel in the later stages of exercise. Despite differing metabolic changes between glucose and fructose, there appears to be no additional performance benefit of ingesting fructose during exercise (Massicotte et al., 1989). Additionally, fructose takes longer to appear in the blood due to its conversion to glucose in the liver (Chen et al., 1977), and may produce symptoms of gastrointestinal discomfort. Similarly, no differences in exercise performance compared with glucose have been observed with sucrose, maltodextrin, or glucose polymers (Massicotte et al., 1989; Flynn et al., 1987)

Gastric Emptying

Another of the concerns with regard to a carbohydrate beverage involves how quickly it will move through the gastrointestinal tract. Gastric emptying and intestinal absorption influence this process. The first component, or gastric emptying is the rate at which fluid or food is passed through the stomach. Although gastric emptying is affected to some extent by, osmolality, pH, exercise and stress (Maughn and Leiper, 1999), it appears that the volume and energy density of the meal have the greatest impact. One of the most important variables with regard to gastric emptying is the volume of the fluid passing through the stomach. It has been shown that a direct relationship exists between the amount of fluid ingested and the rate of gastric emptying, which will occur up to a volume of 600ml (Costill, 1992). Another factor that has been speculated to influence the rate of gastric emptying is the osmolality of a beverage. However, in a study comparing the gastric emptying rates of a 10% glucose solution, a 10% glucose polymer solution, and water, Owen et al.(1986) observed similar rates of gastric emptying between the

glucose and glucose polymer solutions despite large differences in osmolalities between the two. Although it has previously been demonstrated that the osmolality of the solution may have an impact on the rate of gastric emptying it appears that this may be limited to solutions having high concentrations of solute ($>10\%$). The initiation of exercise may also have an impact on the rate of gastric emptying. It has previously been shown that when exercise intensity exceeds 80% VO_2 max there is a reduction in the rate of gastric emptying. In a study comparing the gastric emptying rates of a carbohydrate solution during both swimming and running at 75% VO_2 max, Houmard et al.(1991) found no differences in the rate of gastric emptying between rest and exercise and between modes of exercise. It appears that the intensity of exercise must exceed 75% VO_2 max, for gastric emptying to be affected. The mechanisms for this is most likely explain this decrease is the shunting of blood away from the GI tract and towards the working muscles.

Intestinal Absorption

After the fluid is successfully emptied from the stomach it must then be absorbed from the intestine before it will present itself in the blood. Intestinal absorption is an active process that is responsible for moving the ingested glucose into the bloodstream. Unlike gastric emptying, intestinal absorption is a process that is largely influenced by the osmolality of the solution. The higher the osmolality of the solution, the slower the rate of intestinal absorption. Since increasing the concentration of carbohydrate in a solution will generally increase the osmolality, there is a need to balance the osmolity of the solution with the amount of carbohydrate that is added to the solution. This has led to research examining different forms of carbohydrate in an effort to change the osmolality of the solution without affecting the caloric content. One of the most studied of these alternatives are glucose polymers. In comparison to glucose solution, a glucose polymer solution will have a significantly lower osmolality while maintaining the same amount of carbohydrate. It has been hypothesised that a lower osmolality

solution will result in a greater rate of intestinal absorption, and a more readily available source of carbohydrate in the blood during exercise. In a study comparing the effect of beverage osmolality on the rate of fluid absorption during exercise, Gisolfi et al. (1998) compared the intestinal absorption of four beverages of differing osmolalities. The results indicated that all three carbohydrate beverages had intestinal absorption rates that were similar to water within the osmotic range studied. The reason for the similarity was more than likely due to the moderate osmolality of the solution, which may have not been sufficient to cause any significant disturbance in absorption. Although lower osmolality solutions may offer some advantage in terms of intestinal absorption the effect on performance and metabolic changes has been shown to be slight. Marricotte et al. (1989) compared the endocrine and metabolic responses between fructose, glucose, and a glucose polymer during prolonged exercise. No differences were observed between glucose polymer and glucose in terms of carbohydrate oxidation, and blood glucose concentration. The investigators suggested that there is no advantage in terms of performance by ingesting glucose polymer over glucose and that despite the lower osmotic pressure of the 10% glucose polymer, it is not delivered to the blood more quickly than the 10% free glucose solution. It appears then that as long as the osmolality of the solution remains within a moderate range there is no need to replace glucose with glucose polymers when selecting a carbohydrate solution.

2.0 Methodology

2.1 Experimental Design

This study was a single group repeated measures design involving three counterbalanced trials to determine the effect of pre-exercise carbohydrate ingestion on high intensity swimming performance lasting approximately 1 hour.

2.2 Subjects

Ten well-trained male athletes between the ages of 18-35 were recruited to participate in the study from the UBC campus and Vancouver area. Each of the subjects was either an active long distance swimmer or triathlete. These individuals were chosen because of their familiarity with the duration and intensity of the 4000m swim. Subjects were chosen based on the following inclusion criteria: male, between the ages of 18-35, a VO_2 max of $>45\text{ml}\cdot\text{kg}\cdot\text{min}^{-1}$ based on a tethered swimming protocol, ability to swim the 4000m within 80minutes, and no history of diabetes mellitus. These guidelines were used so as to ensure homogeneity between subjects. Subjects were also informed that they must be available for testing at the same time each of the three testing days. All testing was conducted at 7am with each trial being separated by 5-7 days. Prior to involvement in the study each subject was informed of all potential risks and benefits associated with participating and provided written consent under the guidelines of the UBC Clinical Research Ethics Board policies for the use of human subjects. All subject data and information was kept confidential and stored in a locked cabinet accessible only by the primary investigators.

2.3 Procedures

2.3.1 Preliminary Testing

An initial testing session was conducted one week prior to the start of the first trial in order to gather descriptive data and provide subjects with guidelines for participation. Descriptive data included; height, weight, age, %body fat and $\dot{V}O_2$ max. $\dot{V}O_2$ max was measured using a tethered swimming protocol which has previously been shown to have a test-retest reliability or $r=0.93$ (Magel and Faulkner, 1967) and a high correlation ($r=0.99$) to free swimming (Bonen et al., 1980).

Body Fat Determination

Body fat was measured using Hydrostatic Weighing. The subjects were required to sit on a platform attached to a scale. At the commencement of the trial the subject began to exhale as much air as possible while lowering their head into the water. After a steady weight was recorded the subject was notified to lift their head out of the water. The procedure was repeated twice more to obtain a consistent measure. Following the determination of water temperature body fat was subsequently calculated using:

$$\text{Density} = \frac{W}{\frac{(W - UWW)}{C} - RV}$$

Where W = weight on land (kg)
 UWW = under water weight (kg)
 RV = residual volume
 C = temperature correction

Body density was then converted to percent body fat using the Siri equation:

$$\% \text{Fat} = \left(\frac{495}{\text{density}} - 4.5 \right) * 100$$

Tethered Swimming V02 max

The testing session was conducted in a roped off section of the UBC Aquatic Centre. Prior to reporting to the lab each subject was asked to refrain from caffeine and alcohol for 4 hours prior to the testing and no food for two hours prior to the start of the test. Each subject was fitted with a Polar Accurex Plus heart rate monitor (Woodbury, NY) and a custom made shoulder harness to avoid movement during swimming. The subjects were then fitted with a waist harness attached to metal loops on either side of the belt. Through each belt loop was attached a 125cm piece of nylon rope which was subsequently fitted to both ends of a 1m wooden dowel. This was done to ensure that the rope did not interfere with the subject's leg movement during swimming. On the reverse side of each end of the dowel was attached 75cm of nylon rope that was joined together using a metal clamp. From this clasp a single piece of 70cm nylon rope led back to a pulley system on the deck of the pool. The rope was threaded through two pulleys and ultimately to a hanging bucket, which would be loaded with weight during the trial.

Prior to beginning the test the subject performed a 5-min self paced warm-up with the tethered swimming apparatus using the load that would be used at the beginning of the test. The fitness levels of the subjects determined the initial loading of the tethered apparatus. Once the subject had completed a suitable warm-up they were fitted with a nose plug and modified mouthpiece and headgear apparatus that would allow them to remain with their head under water throughout the duration of the test. A 1.5m long corrugated flexible plastic tube was connected to the intake side of the mouthpiece to allow the subject to breathe room air. A similar tube was attached to the output side of the mouthpiece for the collection of expired gases, which was analysed every thirty seconds using a Beckman Metabolic Cart. A Beckman Oxygen analyzer model OM-11 (Schiller Park, Illinois) and a Beckman Medical Gas Analyzer (Schiller Park, Illinois) recorded measurements of oxygen and carbon dioxide respectively. At the commencement of the test the subject was instructed to maintain a fixed position in the pool which was visible to the subject by the use of a weighted marker. If the subject began to stray from this position they were given verbal warnings through the intake hose, of which the subjects

reported to hear very well. The test started with an initial resistance of either 2.0 or 3.0kg, and was increased by an additional 500g each minute using a step protocol. The test termination criteria included; a plateau, decrease, or increase of less than or equal to 2ml·kg·min of oxygen consumption at the end of each minute of the testing, an RER greater than 1.10.

2.3.2 Subject Guidelines

In order to keep the variance in endogenous glycogen levels similar between trials the subjects were provided with exercise and dietary guidelines prior to the first day of testing. Exercise guidelines included: no intense exercise 48 hours and no exercise 24 hours prior to the exercise trial in order to control for any exercise induced decreases in muscle glycogen levels. In order to control for any variance that may occur within the subject's diet, the subjects were required to keep a dietary record for 48 hours prior to the first trial. The dietary log included the type, quantity, and timing of food and drink that was consumed 48 hours prior to the trial. The results of the dietary log were analysed for nutritional makeup upon completion of the trial. In order to keep some consistency between trials the subjects were instructed to replicate the same diet prior to each subsequent trial. To control for any fluctuations that may occur with liver glycogen, subjects were required to fast for 12 hours prior to reporting to the lab.

2.3.3 Testing Protocol

The performance trial consisted of three sessions conducted in random order separated by seven days. On the testing day the subjects reported to the lab following a 12-hour fast, and 45 minutes prior to the start of their performance trial. Upon arrival at the lab the subjects were weighed and resting blood glucose was taken. A 25microlitre blood sample was obtained using a YSI Model 1502 capillary tube holder/injector (Yellow Springs, Ohio), and analysed using a one touch II- blood glucose analyser (Lifescan Burnaby B.C.). Subsequent blood glucose samples were obtained at five-minute intervals up until ten minutes prior to the performance trial. Prior to

each of the scheduled trials, the subjects were required to consume two beverages at two different feeding times (See Figure 2.3). The first beverage was consumed 35 minutes prior to exercise, followed by a second feeding 5 min prior to the start of exercise. The content of each of the beverages was dependent on one of the three trial conditions. There were three reasons for conducting the feeding trials in this manner. Firstly it blinded the experimenter as to the content of the fluid. If only one drink was used it would alert the experimenter as to the timing of the active drink. Secondly, it kept the volume of fluid similar between trials at the onset of exercise. The consumption of fluid immediately prior to exercise may have an influence on the way the subjects are able to perform the performance trial. Thirdly, since the subjects were a well-trained and experienced group, who may have previous experience and biases regarding the timing of carbohydrate beverages, it blinded the subjects as to the nature of the supplementation. The glucose beverage consisted of $5\text{ml}\cdot\text{kg}^{-1}$ of a 10% glucose solution. The concentration and volume were chosen to allow for a suitable gastric emptying and a glucose amount of between $30\text{-}50\text{g}\cdot\text{hr}^{-1}$ (Gisolfi, 1992). The placebo beverage was of similar taste and colour. The contents of the drinks were blinded from the experimenter and were coded by a lab technician prior to each trial. After consuming the first beverage the subjects assumed a rested position for thirty minutes, at which time the second beverage was consumed. Five minutes following the ingestion of the second beverage the subjects began a 100m self-paced swimming warm-up prior to the performance trial. The performance trial consisted of a 4000m-timed swim using the 50meter lengths in order to avoid the number of turnovers at the end of the pool. The subjects were instructed to swim the required distance in the fastest time possible, during which time the subjects were provided feedback in the form of a visual cue each 1000m. At 2000m and 4000m each subject was stopped to provide their rating of perceived exertion on a 20-point Borg Scale. During the performance trial heart rate was recorded and stored using a Polar Accurex Plus heart rate monitor. At the end of the 4000m swim the subject quickly exited the pool at which time blood glucose and lactate measures were taken. Blood was obtained using a $25\mu\text{L}$ microcapillary

tubule and a YSI microcapillary injector. Blood glucose was again analysed using a One-Touch blood glucose analyser at zero, five and ten minutes post-exercise. Blood lactate was determined using a YSI 1501 Lactate Analyzer (Yellow Springs, Ohio). Blood lactate samples were taken at zero, two and four minutes post-exercise. Recovery heart rate was also acquired for ten minutes in the post-exercise period. Prior to departure from the lab the subjects were queried with regard to subjective feelings prior to, during and after the exercise trial.

TABLE 1. FLUID CONTENT OF EACH OF THE TRIALS.		
<u>Trial</u>	<u>Content of Feeding 1</u> (35 min pre-exercise)	<u>Content of Feeding 2</u> (5 min pre-exercise)
Trial 1	5ml·kg ⁻¹ 10% glucose solution	Placebo
Trial 2	Placebo	5ml·kg ⁻¹ 10% glucose solution
Placebo	Placebo	Placebo

2.5 Data Analysis

Independent Variables

1. Timing of the pre-exercise feeding.
2. Content of the beverages.

Dependent Variables

1. Time required to complete the performance trial.
2. Pre and Post exercise blood glucose.
3. Post exercise lactate.

4. Heart rate during the performance trial.
5. Total calories and carbohydrates between trials.
6. Rating of perceived exertion.

Statistical analysis was conducted using a one way repeated measures analysis of variance to determine significant difference between means with regard to total time, split time, post-exercise blood glucose and lactate, average heart rate, and rating of perceived exertion. When appropriate, post-hoc analysis was conducted to determine any significant difference between means using a Bonnferronni t-test. An alpha level of .05 was used for all statistical analysis.

Results

Subject Characteristics

Twelve male triathletes volunteered for participation in this study. Of these, ten subjects completed the study, while two withdrew due to personal commitments. Subject characteristics are presented in Table 2

TABLE 2: Subject Characteristics

Subject	Age (yrs)	Height (cm)	Weight (kg)	Body Fat (%)	V02max (ml·kg·min ⁻¹)	V02max (L·min ⁻¹)
1	34	180.2	72.1	11.4	51.2	3.66
2	34	178.6	71.5	6.5	49.4	3.53
3	28	180.0	82.5	15.1	45.5	3.75
4	28	178.2	72.6	7.1	50.5	3.66
5	19	171.2	62.7	12.1	55.6	3.49
6	28	187.9	78.5	7.7	46.9	3.63
7	25	182.5	79.2	11.2	47.3	3.75
8	34	182.1	75.1	16.7	46.3	3.46
9	30	186.8	89.5	13.6	**	**
10	35	180.1	80.2	9.8	46.7	3.74
$\bar{X}$	29.5	180.7	76.4	11.1	48.8	3.6
SD	5.0	7.3	7.3	3.4	3.2	0.1

**Denotes missing sample.

Performance Time

Performance time was analyzed with a one-way repeated measures ANOVA using SPSS version 8.0. Although significance between the three trials was initially observed ($p=0.004$), Bonnferroni post-hoc testing revealed no significant difference between the means ($\bar{X} \pm SD$: G⁵ 70.7 ± 7.6

min, G³⁵ 70.1 $\pm$ 7.6 min, PL 71.9 $\pm$ 8.4 min). Individual times are listed in Table 3. No test order effect was observed between the three trials ($p=.69$).

Table 3. Individual performance times (min) for each subject

Subject	G5	G35	Placebo
1	64.7	64.2	64.1
2	69.0	69.7	70.2
3	80.3	78.5	80.7
4	78.6	79.3	83.6
5	68.8	66.8	70.9
6	74.9	73.7	75.6
7	67.5	67.1	66.9
8	72.4	73.2	75.0
9	76.3	74.5	77.0
10	54.5	53.9	54.9
$\bar{X}$	70.7*	70.1*	71.9*
SD	7.6	7.6	8.4

G5- Subject ingested glucose solution 5 minutes prior to exercise

G35- Subject ingested glucose solution 35 minutes prior to exercise

Placebo- Subject ingested an isocaloric solution prior to exercise.

* Denotes non-significance between means

Splits were recorded each 1000m to determine if pace varied over the exercise time. During all trial conditions there was a trend towards a decrease in performance as time progressed. There was no significant difference in the lap times between any of the trials.

G5- Subject ingested glucose solution 5 minutes prior to exercise
 G35- Subject ingested glucose solution 35 minutes prior to exercise
 Placebo- Subject ingested an isocaloric solution prior to exercise.

Blood Glucose

Blood glucose levels immediately prior to exercise were significantly different ($p < .0001$) between G³⁵ ($8.36 \pm 1.1 \text{ mmol/L}$) compared with G⁵ ($5.24 \pm 0.51 \text{ mmol/L}$) and Placebo ($5.3 \pm 0.44 \text{ mmol/L}$), with no significant difference between G⁵ and Placebo. No significant differences

were observed between any of the post-exercise measurements at 0min post(G^5 5.06 ± 0.95 mmol/L, G^{35} 5.06 ± 1.13 mmol/L, PL 4.99 ± 0.79 mmol/L), 5min post (G^5 5.35 ± 0.81 mmol/L, G^{35} 5.25 ± 1.1 mmol/L, PL 5.11 ± 0.7 mmol/L), and 10min post(G^5 5.23 ± 0.76 mmol/L, G^{35} 4.93 ± 0.75 mmol/L, PL 4.94 ± 0.58 mmol/L). Individual blood glucose values are reported in Table 7 of Appendix A.

Blood Lactate

Post-exercise blood lactate measurements were non-significant between measures at 0min post (G^5 3.2 ± 1.4 mmol/L, G^{35} 3.9 mmol/L ± 1.1 mmol/L, PL 3.3 ± 1.3 mmol/L), 2min post(G^5 3.13 ± 1.3 mmol/L, G^{35} 3.43 ± 1.1 mmol/L, PL 2.75 ± 1.1 mmol/L), and 4min post(G^5 2.9 ± 1.2 mmol/L, G^{35} 3.2 ± 1.3 mmol/L, PL 2.9 ± 1.4 mmol/L). Individual blood lactate values for each trial condition are listed in Table 6 in Appendix A.

Heart Rate

Heart rate was recorded and averaged over the course of the entire swim. No significant difference in heart rate was observed between groups ($p > .05$) using a repeated measures ANOVA. Average heart rate for each condition is reported in Table 4 with individual heart rates for each trial condition listed in Table 8 of Appendix A.

Table 4. Average heart rate for each trial condition.

	G ⁵	G ³⁵	Placebo
$\bar{X}$	153.6	155.8	152
SD	12.6	10.8	12.5

G⁵- Subject ingested glucose solution 5 minutes prior to exercise

G³⁵- Subject ingested glucose solution 35 minutes prior to exercise

Placebo- Subject ingested an isocaloric solution prior to exercise.

Rating of Perceived Exertion

A 20 point Borg scale was used to determine rating of perceived exertion for each trial condition.

No significant differences were observed between overall RPE and the three trials (G⁵ 14.5 ± 0.9 , G³⁵ 14.9 ± 1.5 , PL 14.5 ± 1.1). Individual RPE are listed in Table 9 of Appendix A.

Dietary Records

In order to maintain a consistent caloric and carbohydrate intake prior to each trial subjects were required to keep a detailed dietary log for 48 hours prior to each trial. Each log was analyzed for

total calories and carbohydrates using Recipe Calc 3.0. No significant difference between trials was observed for either total calories or carbohydrates ($p>.05$). Mean totals for each trial are reported in Table 5 with individual totals reported in Table 10 of Appendix A.

TABLE 5. Mean dietary content prior to each trial

	G5	G35	PL
Total Calories (kcal)	5607±648	5545±682	5702±670
Total Carbohydrates (g)	899±66	870±92	911±71

G5- Subject ingested glucose solution 5 minutes prior to exercise
G35- Subject ingested glucose solution 35 minutes prior to exercise
Placebo- Subject ingested an isocaloric solution prior to exercise.

Discussion

The goal of this study was to investigate the effect on performance of ingesting a solution of glucose prior to swimming a fixed distance lasting approximately 60 minutes. As well as to determine if the timing of the glucose feeding would have any effect on performance. The main finding of this study was that no statistical difference in swimming performance was observed following the ingestion of the glucose solution, either 5 or 35 minutes prior to exercise. Although a significant difference was observed between means following repeated measures ANOVA, this difference became non-significant with additional Tukey's post-hoc analysis. The high correlation within trials was suggestive of a clear trend for performance improvement following the glucose trials, however the greatest difference between means was only the 2.5% observed between the placebo and glucose ingested thirty-five minutes prior to exercise.

The subjects in the study were trained triathletes who were currently engaged in regular aerobic exercise, despite having finished their competitive season approximately 6-8 weeks earlier. Measurements of aerobic power were determined using a previously validated tethered swimming method (Kohrt et al., 1987). Maximal oxygen consumption values are similar to those previously observed in triathletes (Kohrt et al., 1987; Flynn et al., 1990; O'Toole et al., 1995). Statistical analysis of each of the subjects' dietary logs indicates that each subject arrived at the lab having consumed similar amounts of total calories and carbohydrates prior to each trial. As well the percentage of calories derived from carbohydrates, protein and fat was similar between subjects using a repeated measures ANOVA.

Exercise Mode

One of the unique aspects of this study was that it employed swimming as the mode of exercise. Previous research involving carbohydrate ingestion prior to exercise lasting one hour has primarily examined cycling. There has been only a limited amount of research investigating other exercise modes, with virtually none utilizing whole body exercise. It has previously been demonstrated that there are certain physiological differences that exist between arm and leg exercise with respect to fuel utilisation. Several investigators have observed an increase in the fractional extraction of blood glucose, a higher lactate output from the exercising muscle, a significantly lower post-exercise blood glucose concentration, and a greater reliance on hepatic glycogen with arm exercise (Ahlborg et al.,1986; Ahlborg and Wahren.,1991) or swimming (Lavoie 1982, Flynn et al.,1990). Based on these previously observed differences, it was somewhat surprising that there was no significant improvement in performance following either of the glucose trials. It was hypothesized that the combination of an overnight fast (designed to lower liver glycogen) and the introduction of a mode of exercise previously shown to utilize carbohydrate to a greater degree would exhibit a difference in performance if no exogenous carbohydrate source was introduced. One possible explanation for a lack of improvement may involve the training status of the subjects. It has previously been observed that following aerobic training, there is a decrease in muscle glycogen utilization and a greater shift towards fat oxidation during exercise (Coggan and Coyle 1991) This will ultimately result in a sparing of endogenous glycogen and a delay in fatigue. Several studies that have examined arm versus leg exercise have primarily used untrained subjects , unlike the trained group used in the present study. If training did in fact decrease the reliance on muscle glycogen, it is conceivable that exercise of this distance was insufficient to noticeably decrease muscle or liver glycogen. This

explanation appears unlikely however since similar differences in arm and leg exercise have been observed in trained individuals (Flynn et al., 1990) and an increase in glycogen degradation with arm exercise has been shown to be independent of training status (Ahlborg et al., 1991). Another possible explanation may be related to the involvement of the liver during exercise. Although arm exercise will result in a greater utilization of muscle glycogen and blood glucose, arm exercise provides a greater stimulus for the uptake of gluconeogenic precursors in the liver (Ahlborg et al., 1986). This may represent a means by which a greater utilisation of carbohydrate is offset by an increase in supply, thereby maintaining euglycemia observed in the present trial.

Ingestion 35 minutes prior to exercise

One of the unique aspects of this study was that it compared the effects of a glucose solution at two different feeding times. It has previously been demonstrated (Foster et al., 1977; Costill et al., 1979) that the consumption of a high glycemic solution such as glucose would decrease performance if ingested 35-min prior to exercise. Therefore, athletes selecting carbohydrates prior to exercise needed to choose either a low glycemic solution (Thomas et al., 1991) or adjust the feeding time so that it would be immediately prior to the start of exercise (Neufer et al., 1987). Although there have been numerous studies that have examined the effects of varying glycemic substances with regard to metabolic variables, investigations looking at the effect on performance have been for somewhat absent. The results of the current study indicate that there is no liability in exercise performance when glucose is ingested 35-minutes prior to exercise lasting 60 minutes. Although the length of exercise time during this study was longer than that used by Foster et al. (1977) and Costill et al. (1979), subsequent studies (Devlin et

al.,1986; El-Sayed et al.,1997) have failed to show any decrease in performance with carbohydrate ingestion 30 minutes prior to exercise.

As expected, due to the high glycemic value of the glucose solution, there was a large difference in the blood glucose concentration immediately prior to exercise with the G³⁵ trial ($8.6\text{mmol}\cdot\text{L}^{-1}$) compared with the other trials (G⁵ $5.4\text{mmol}\cdot\text{L}^{-1}$, PL $5.3\text{mmol}\cdot\text{L}^{-1}$). One of the limitations of the present study was the time at which the samples were obtained. To avoid any disturbances to the subjects during the exercise trials, blood sampling was conducted prior to and following exercise. Thus, it is difficult to make conclusions about any trends that may have occurred during exercise. Although insulin was not measured directly in the present study, a similar elevation in insulin would likely have accompanied the rise in glucose observed prior to the onset of exercise (Marmey-Conus et al.,1996; Sparks et al., 1998). The degree of insulin increase has been shown to follow a dose response prior to, but not during exercise (Short et al.,1997). It can also be assumed that in the current study, the high concentration of insulin combined with contraction mediated glucose uptake would have resulted in a decrease in blood glucose at the onset of exercise. Under conditions where liver glycogen levels are normal, blood glucose homeostasis is maintained by an increase in hepatic glucose output. In the presence of glucose ingestion 30 minutes prior to the start of exercise however, the resulting hyperinsulinemia will result in a decrease in glucose output from the liver (Marmey-Conus et al.,1996). In the present study subjects were required to report to the lab following a 12 hour fast. Although liver glycogen was not measured, the length of the fast has formally been shown to result in a significant reduction in hepatic glycogen (Nillson 1973). Since glucose ingestion reduces the rate of hepatic glucose output, it was expected that the extent to which liver glycogen could contribute to blood glucose homeostasis would be reduced due to both the ingestion of

glucose, as well as the overnight fast. The term transient hypoglycemia has been used to describe the hyperinsulemia and subsequent hypoglycemia at the onset of exercise, which may persist for 20-30 minutes (Foster et al.,1977; Costill et al.,1979; Marmy-Conus et al.,1996; Short et al., 1997). In the present study there was no change in either performance time, or subjective measures during this initial period, despite close to a $9 \text{ mmol}\cdot\text{L}^{-1}$ blood glucose concentration prior to the start of exercise, compared with 5 mmol/L with the other two trials. Performance pace was actually highest for all of the subjects during the beginning of exercise, and decreased as exercise time increased. Three subjects during the G^{35} reported feelings of sluggishness and fatigue during the first portion of the swim. However, they reported that it did not have any effect on their ability to maintain their exercise intensity, and disappeared as time progressed. Despite the likely decrease in blood glucose at the onset of exercise in all subjects, post-exercise blood glucose was similar between trials. Previous research suggests that this is likely due to the continuous release of carbohydrate from the gut following glucose ingestion (Marmy-Conus et al.,1996). The post-exercise blood glucose values observed in the present study are consistent with those previously observed following swimming of this duration and intensity (Flynn et al., 1990).

Glucose ingestion 5 minutes prior to exercise

The failure to observe any increase in performance with the G^5 feeding is met with some inconsistency in the literature. Some studies have indicated no change in performance (Powers et al., 1990; Sparks et al., 1997) while others have demonstrated improvements ranging from 2.3% (Jeukendrup et al., 1997) to over 10% (Neufer et al.,1987). The majority of these studies have

used feeding times that were either immediately prior to or during exercise (Anantaraman et al., 1995; Jeukendrup et al., 1997; Neufer et al., 1987; Ball et al., 1995; Below et al., 1995). This approach was likely done as a means to avoid hyperinsulemia and subsequent hypoglycemia (Neufer et al., 1987). This does not appear to be necessary based on the results of the present study. One possible reason for the discrepancy between studies may be related to the differences in the exercise protocols used to measure performance. Two of the more favourable exercise protocols currently employed involve either a moderate intensity exercise period followed by a high intensity performance cycle (Neufer et al., 1987; Below et al., 1995; Ball et al., 1995) or a set distance to be completed in the fastest time possible. One of the obvious differences between these two approaches is that the performance ride at the end of the first trial involves a very high intensity of exercise. Since muscle glycogen depletion increases with a rise in exercise intensity, it could be argued that those studies, demonstrating the greatest improvement in performance, employed an exercise protocol that would have placed the greatest stress on endogenous glycogen levels. On average, the improvement in performance is near 6% in these protocols versus 2.5% in the approach using constant exercise intensity throughout. In the present study, the largest difference in times was 2.5%, a number very similar to the 2.3% difference observed by Jeukendrup et al (1997), using a similar protocol in cyclists.

In agreement with most studies in this area, there was no significant increase in post-exercise blood glucose following glucose ingestion 5-minutes prior to the start of exercise. It was hypothesized that by using a feeding closer to the start of exercise, fluctuations in blood glucose could be avoided while still providing a supply of glucose from the gut during exercise. One of the limitations of interpreting post-exercise blood glucose with exercise of this duration and intensity is that it has been shown to be a poor measure of performance. This is evident in studies

where there is an increase in performance between glucose and placebo trials despite very little difference in blood glucose concentrations (Below et al., 1995). Additional studies have also observed significant differences in blood glucose despite no change in performance (Hargreaves et al., 1987; Thomas et al., 1991). This tends to support the notion that measurements of blood glucose at this intensity of exercise, are poor predictors of the ability to maintain performance. This is likely related to the fact that exercise of this duration and intensity has failed to demonstrate any significant decrease in muscle glycogen (Devlin et al., 1986; Neufer et al., 1987; Hawley et al., 1997).

The lack of a significant difference in average heart rate between any of the trials is consistent with some (Jeukendrup et al., 1997; Ball et al., 1995) but not all studies (Below et al., 1995). It is interesting to note that performance was improved in all three of these studies despite the differences in heart rate. Since an increase in performance was attributed to an increase in exercise intensity, it is somewhat surprising that not all of the studies that observed an increase in performance had a similar elevation in heart rate. This may have been due to the modest increase in workload (Jeukendrup et al., 1997), or the extreme anaerobic nature of the performance measure at the end of exercise in the form of a Wingate test (Ball et al., 1995).

Post-exercise blood lactate values in the current study were similar to those that have been previously observed during swimming (Flynn 1990) however, in agreement with the large majority of studies, there were no differences between trials (Below et al., 1997; Neufer et al., 1987; Devlin et al., 1986). One of the limitations of the present study was that lactate measures were only sampled at the conclusion of the exercise period. This approach means that the post-exercise lactate may only be a reflection of changes at the end of the trial where a sprint may occur. Careful inspection of heart rate and lap time during the last 5% of each swim fail to

support such a theory since neither changed to any significant degree, suggesting that exercise intensity was consistent near the end of each trial.

Glucose versus Placebo

One of the main findings of the present study was that independent of glucose feeding time there was a small but non-significant increase in performance. One of the main conclusions of this study is that the timing of the feeding makes no significant difference to performance. Similar performance times, heart rates, and post exercise blood glucose and lactate values were observed with both of the glucose trials. This has been confirmed in two similar studies in cyclists. Using virtually identical protocols except for the timing of the pre-exercise beverage at 5min (Jeukendrup et al., 1997) and 25min (El-Sayed et al., 1997), an almost identical increase was observed in both the performance improvement and power output during exercise. While both of these studies observed an improvement in performance that was less than 3%, the investigators attributed this to a 44 second improvement during a time trial race, which they concluded to be meaningful. One of the questions regarding any study that employs a trial condition is whether the amount of glucose given is sufficient to elicit the desired effect. In the current study subjects ingested an average of 40g of glucose prior to each of the G⁵ and G³⁵ conditions. This amount has previously been demonstrated to be sufficient to improve performance lasting 60 minutes (Neufer et al., 1987; Below et al., 1995; Anantaraman et al., 1995; El-Sayed et al., 1997; Jeukendrup et al., 1997). It also appears that there is an upper limit to the amount of carbohydrate that is useful in enhancing performance. Anantaraman et al. (1995) observed no additional improvement in performance when a substantially greater amount of glucose (120g vs. 30g / hour) was ingested prior to exercise.

Carbohydrate ingestion, either prior to or during longer duration exercise (>2 hrs) results in an increase in exercise performance, glucose oxidation and blood glucose concentration (Coggan et al., 1989; Tsintzas et al., 1996). In the absence of carbohydrate ingestion, the end of prolonged exercise is marked by a significant decrease in blood glucose, muscle and liver glycogen and carbohydrate oxidation (Coggan et al., 1991). Exogenous carbohydrate is likely to provide the greatest benefit at the end of exercise by maintaining carbohydrate oxidation and ultimately delaying fatigue. It appears that distinct differences are present between high and low intensity exercise with regard to how performance is enhanced in each. In the present study there was no significant decrease or difference in post exercise blood glucose between any of the trials, where the mean post-exercise values for each trial was close to $5 \text{ mmol} \cdot \text{L}^{-1}$. The lowest post exercise blood glucose concentration that was observed was 3.2 mmol/L , occurring in one subject following both of the glucose trials. If this subject was in some way susceptible to hypoglycemia, it is somewhat surprising that it occurred during both instances of carbohydrate ingestion and not with the placebo since the glucose ingested provided a source of carbohydrates. Despite these low blood glucose levels, this subject did not report any differences in RPE or any unusual symptoms other than non-specific fatigue. He described this as similar to that normally experienced during a long swim. It is somewhat curious that in this subject there were no changes in RPE despite a substantial decrease in blood glucose, since lower ratings of perceived exertion have occurred during prolonged endurance exercise following carbohydrate replacement (Lonnet et al., 1991; Wilber et al., 1992; Utter et al. 1999). The most likely explanation is an inverse relationship between blood glucose and the perception of an increase in exertion. In the present study, no significant differences in RPE were observed between any of the trial conditions, with the mean rating between 14-15 for all three trials. If RPE is sensitive to any

changes in blood glucose, it would stand to reason that the failure to notice any difference in RPE in the present study would be conditional on any differences in the blood glucose.

The failure of blood glucose to decrease with exercise of this duration appears to reinforce the idea that blood glucose measures are not a strong indicator of performance or impending fatigue with shorter duration exercise. Although not measured in the current study, it has previously been shown that similar conclusions may be drawn with regard to muscle glycogen and overall glucose oxidation. Unlike prolonged endurance exercise, no decreases in muscle glycogen (Hargreaves et al., 1987; Hawley et al., 1997) or increases in CHO oxidation (Neufer et al., 1987; Below et al., 1995) have been consistently observed during exercise of this intensity. Due to a failure to observe any changes in these variables, the mechanism by which pre-exercise carbohydrate ingestion may improve performance is not fully understood. In those studies that have measured performance during various stages of the exercise period, there is a noticeable decrease in performance towards the latter stages of exercise. In the present study performance time was observed during various stages of the swim in order to determine if performance changes may be time dependent. Figure 1 in the results section shows split times for each of the four 1000m periods during the three trials. There is a trend toward slower split times near the end of the three swims, with the greatest decrease occurring during the placebo (-7.5%) compared with the glucose trials (G^5 -4.4%, G^{35} -4.5%). A similar trend was observed by Anantaraman (1995), in which subjects were required to maintain a high level of cycling intensity following the ingestion of either a placebo or glucose solution. The subjects attempted to maintain an exercise intensity that corresponded to 90% $\dot{V}O_{2\max}$ throughout the 60 minute exercise trial. Although all groups demonstrated some decrease in power output near the end of exercise, the drop was most noticeable in the placebo group during the last 25% of the ride.

Comparatively, during the glucose trial, subjects were able to maintain a higher work output near the end of exercise, resulting in a 14% less decrease in power output. It was speculated by Anantaraman et al.(1995) that the performance improvement after 40 minutes may have been due to a decrease in muscle glycogen. Such a decrease would result in a decline in power output if a sufficient exogenous source was not introduced. It is doubtful that this provides an adequate explanation based on a study conducted by Hargreaves et al.(1997). Using a very similar cycling protocol to the one employed by Anantaraman et al.(1995), Hargreaves et al.(1997) compared cycling performance over 60 minutes between a placebo with normal levels of muscle glycogen and a trial group with elevated levels of muscle glycogen. The results indicated that there were no differences in performance time between groups, and that there was still a sufficient quantity of muscle glycogen in the control group following the cycle. This issue is further clouded by the fact that it has not been consistently shown that performance during exercise at this intensity and duration is the result of any increase in glucose oxidation (Neufer et al. 1987; Below et al.,1995)

In order to maintain the double blind protocol, the subjects consumed the same amount of fluid under all three conditions. In a previous study by Below et al.(1995) cycling in a moderately warm environment, both water and a carbohydrate solution each demonstrated a 6% improvement in cycling performance. The investigators attributed the improvement by water alone to an attenuation in body temperature. In a milder environment (20° C vs. 31° C), Robinson et al.(1995) found no improvement during 60 minutes of cycling with water ingestion alone. These studies appear to indicate that any benefit during 60minutes of exercise obtained from ingesting water is the result of an attenuation in body temperature. In comparison, the present study was conducted in a pool that displayed a mean temperature of 29.1°C. Previously research has demonstrated that this temperature contributes to a minimal amount of heat stress

while exercising (Galbo et al, 1979). Although the present study did not employ a trial void of fluid, it is doubtful that water only would have contributed to any improvement in swimming performance. One of the questions prior to the study was the effect that this relatively large amount of fluid would have on the subjects' subjective feelings of gastrointestinal distress. Prior to engaging in their first trial, there were two subjects who expressed slight apprehension about the amount of fluid they would be ingesting. Although the frequency was relatively small, a slight increase in feelings of fullness in approximately 5 of the 30 trials, which was reported, but it did not impair performance. None of the subjects reported any increased incidences of cramping, general GI distress, or an increased need to urinate during the exercise period.

Summary

This was the first study examine swimming performance of this duration following the ingestion of a glucose solution, and to compare the effects of the timing of the feedings on performance. The results of the present study indicate that there is no improvement in swimming performance when glucose is ingested either 5 or 35 minutes prior to exercise. Although the majority of the subjects showed some degree of improvement with glucose trials the average improvement was only 2.5% and did not reach statistical significance. This occurred, despite a large difference in the concentration of blood glucose between trials at the onset of exercise. During exercise similar heart rates and split times were observed between trials. Near the end of the exercise trial there was a noticeable but non-significant trend towards a widening of split times between the glucose and placebo trials. Although previous studies that have been conducted on cyclists have shown a greater improvement in performance, the mechanism by

which it occurs is largely unknown and may be different than that which occurs during longer duration swimming.

REFERENCES

1. Ahlborg G., J. Wahren, P. Felig. Splanchnic and peripheral glucose and lactate metabolism during and after prolonged arm exercise. *J Clin Invest.* Vol 77, 690-699, 1986.
2. Ahlborg G. M. Jensen-Urstad. Metabolism in exercising arm vs. leg muscle. *Clin Physiol.* Vol 11, 459-468, 1991.
3. Anantaraman R., A.A. Carmines, G.A. Gaesser, A. Weltman. Effects of carbohydrate supplementation on performance during 1 hour of high-intensity exercise. *Intl J Sports Med.* Vol 16, 461-465, 1995.
4. Ball T., S.A. Headley, P.M. Vanderburgh, J.C. Smith. Periodic carbohydrate replacement during 50 min of high intensity cycling improves subsequent sprint performance. *Intl J Sports Nutri.* Vol 5, 151-158, 1995.
5. Below P.R., R. Mora-Rodriguez, J. Gonzalez-Alonso, E. Coyle. Fluid and carbohydrate ingestion independently improve performance during 1 hour of intense exercise. *Med Sci Sports Ex.* Vol 27, 200-210, 1995.
6. Bonen A., S.A. Malcolm, R.D. Kilgour, K.P. MacIntyre, A.N. Belcastro. Glucose ingestion before and during intense exercise. *J Appl Physiol.* Vol 50, 766-771, 1981.
7. Chen, M. R.L. Whistler. Metabolism of D-fructose. *Adv Carb Chem Biochem.* 34:265-343, 1977.
8. Coggan A.R., E.F. Coyle. Carbohydrate ingestion during prolonged exercise: effects on metabolism and performance. *Ex Sports Sci Rev.* 1-40, 1991.
9. Coggan A., E.F. Coyle. Effect of carbohydrate feedings during high-intensity exercise. *J Appl Physiol.* Vol 65, 1703-1709, 1988.
10. Costill D.L., M. Hargreaves. Carbohydrate nutrition and fatigue. *Sports Med.* Vol 13, 86-92, 1992.
11. Costill D.L., E. Coyle, G. Dalsky, W. Evans, W. Fink. *J Appl Physiol.* Vol 43, 695-699, 1977.
12. Devlin J.T., J. Calles-Escandon, E.S. Horton. Effects of preexercise snack feeding on endurance cycle exercise. *J Appl Physiol.* Vol 60, 980-985, 1986.
13. El-Sayed M.S., J. Balmer, A.J. Rattu. Carbohydrate ingestion improves endurance performance during a 1h simulated cycling time trial. *J Sports Sci.* Vol 15, 223-230. 1997.

14. Flynn M.G., D.L. Costill, J.A. Hawley, W.J. Fink, P.D. Influence of selected carbohydrate drinks on cycling performance and glycogen use. *Med Sci Sports Ex.* Vol 19, 37-40, 1987.
15. Flynn M.G., D.L. Costill, J.P. Kirwan, J.B. Mitchell, J.A. Houmard. Fat storage in athletes: metabolic and hormonal responses to swimming and running. *Intl J Sports Med.* Vol 11, 433-440, 1990.
16. Foster C., D.L. Costill, W.J. Fink. Effects of preexercise feedings on endurance performance. *Med Sci Sports Ex.* Vol 11, 1-5, 1979.
17. Galbo H., M.E. Houston, N.J. Christensen, J.J. Holst, B. Nielsen. The effect of water temperature on the hormonal response to prolonged swimming. *Acta Physiol Scand.* Vol 105, 326-337, 1979.
18. Gisolfi C.V., S.M. Duchman. Guidelines for optimal replacement beverages for different athletic events. *Med Sci Sports Ex.* Vol 24, 679-687, 1992.
19. Gisolfi C.V., R.D. Summers, H.P. Schedl, T.L. Bleiler. Effect of sodium concentration in a carbohydrate-electrolyte solution on intestinal absorption. *Med Sci Sports Ex.* Vol 27, 1414-1420, 1995.
20. Gisolfi C.V., R.W. Summmers, G.P. Lambert. Effect of beverage osmolality on intestinal fluid absorption during exercise. *J Appl Physiol.* Vol 85, 1941-1948, 1998.
21. Hargreaves M., D.L. Costill, A. Katz. Effect of fructose ingestion on muscle glycogen usage during exercise. *Med Sci Sports Ex.* Vol 17, 360-363, 1985.
22. Hargreaves M., D.L. Costill, W.J. Fink, D.S. King. Effect of pre-exercise carbohydrate feedings on endurance cycling performance. *Med Sci Sports Ex.* Vol 19, 33-36, 1987.
23. Hargreaves M., J.P. Finn, R.T. Withers, J.A. Halbert. G.C. Scroop, M. Mackay. Effect of muscle glycogen availability on maximal exercise performance. *Eur J Appl Physiol.* Vol 75, 188-192, 1997.
24. Hawley J, L. Burke. Effect of meal frequency and timing on physical performance. *British J Nutri*, Vol 77. S1:S91-S103, 1997.
25. Hawley J.A., G.S Palmer, T.D. Noakes. Effects of 3 days of carbohydrate supplementation on muscle glycogen content and utilisation during a 1 hour cycling performance. *Eur J Appl Physiol.* Vol 75, 407-412, 1997.
26. Hollenbeck C.B., A.M. Coulston. The clinical utility of the glycemic index and it's application to mixed meals. *Can J Physiol Pharmacol.* Vol 69, 100-107, 1990.
27. Holmer I., U. Bergh. Metabolic and thermal response to swimming in water at varying temperatures. *J Appl Physiol.* Vol 37, 702-705, 1974.

28. Hooker S.P., C.L. Wells, M.M. Manroe, S.A. Philip. Differences in epinephrine and substrate responses between arm and leg exercise. *Med Sci Sports Ex.* Vol 22, 779-784, 1990.
29. Houmard J.A., P.C. Egan, R. Anderson, P.D. Neufer. Gastric emptying during 1 hour of cycling and running at 75% VO₂ max. *Med Sci Sports Ex.* Vol 23, 320-325, 1991.
30. Jensen-Urstad M., G. Ahlborg, K.Sahlin. High lactate and NH₃ release during arm and leg exercise is not due to B-adrenoceptor stimulation. *J Appl Physiol.* Vol 74, 2860-2867, 1993
31. Jeukendrup A., F. Brouns, J.M. Wagenmakers. Carbohydrate-electrolyte feedings improve 1 hour time trial cycling performance. *Intl J Sports Med.* Vol 18, 125-129, 1997.
32. Kohrt W.M., D.W. Morgan, B. Bates. Physiological responses of triathletes to maximal swimming, cycling and running. *Med Sci Sports Ex.* Vol 19, 51-55, 1987.
33. Koivisto V. Glycogen depletion during prolonged exercise: influence of glucose, fructose or placebo. *J Appl Physiol.* Vol 58, 731-737, 1985.
34. Lavoie J.M. Blood metabolites during prolonged exercise in swimming and leg cycling. *Eur J Appl Physiol.* Vol 48, 127-133, 1982.
35. Liebman M., J.G. Wilkinson. Carbohydrate Metabolism and Exercise in Nutrition in Exercise and Sport, 2nd edition. CRC Press Inc, 1994.
36. Magel J.R., J.A. Faulkner. Maximum oxygen uptakes of college swimmers. *J Appl Physiol.* Vol 22, 929-938, 1967.
37. Marmy-Conus N., S. Fabris, J. Proietto, M. Hargreaves. Preexercise glucose ingestion and glucose kinetics during exercise. *J Appl Physiol.* Vol 81, 853-857, 1996.
38. Massicotte D., F. Peronnet, G. Brisson, K. Bakkouch, C.H. Marcel. Oxidation of a glucose polymer during exercise: comparison with glucose and fructose. *J Appl Physiol.* Vol 66, 179-183, 1989.
39. Maughan R.J., J.B. Leiper. Limitations to fluid replacement during exercise. *Can J Appl Physiol.* Vol 24, 173-187, 1999.
40. Mitchell J.B., D.L. Costill, J.A. Houmard. M.G. Flynn. Effects of carbohydrate ingestion on gastric emptying and exercise performance. *Med Sci Sports Ex.* Vol 20, 110-115, 1988.
41. Murray R., G.L. Paul, J.G. Seifert, D.E. Eddy. The effects of glucose, fructose, and sucrose ingestion during exercise. *Med Sci Sports Ex.* Vol 21, 275-282, 1989.

42. Neuffer P.D., D.L. Costill, M.G. Flynn, J.P. Kirwan. Improvements in exercise performance: effects of carbohydrate feedings and diet. *J Appl Physiol*. Vol 62, 983-988, 1987.
43. Nillson H.L. Liver glycogen content in man in the postabsorptive state. *Scand J Clin Lab Invest*. Vol 32, 317-323, 1973.
44. O'Toole M.L., P.S. Douglas. Applied physiology of triathlon. *Sports Med*. Vol 19, 251-267, 1995.
45. Owen M.D., K.C. Kregel, P.T. Wall. Effects of ingesting carbohydrate beverages during exercise in the heat. *Med Sci Sports Ex*. Vol 18, 568-575, 1986.
46. Palmer G.S., M.C. Clancy, J.A. Hawley, I.M. Rodger, L.M. Burke. Carbohydrate ingestion immediately before exercise does not improve 20km time trial performance in well trained cyclists. *Intl J Sports Med*. Vol 19, 415-418, 1998.
47. Robinson T.A., J.A. Hawley, G.S. Palmer, G.R. Wilson, D.A. Gray. Water ingestion does not improve 1-hour cycling performance in moderate ambient temperatures. *Eur J Appl Physiol*. Vol 71, 153-160, 1995.
48. Sasaki H., J. Maeda, S.Usui, T. Ishiko. Effect of sucrose and caffeine ingestion on performance of prolonged strenuous exercise. *Intl J Sports Med*. Vol 8, 261-265, 1987.
49. Shepard R.J., P. Leatt. Carbohydrate and fluid needs of the soccer player. *Sports Med*. Vol 4, 164-176, 1987.
50. Sherman W.M., M.C. Pedan, D.A. Wright. Carbohydrate feedings 1 hour before exercise improves cycling performance. *Am J Clin Nutri*. Vol 54, 866-870, 1991.
51. Short K.R., M. Sheffield-Moore, D.L. Costill. Glycemic and Insulinemic responses to multiple preexercise carbohydrate feedings. *Intl J Sports Nutri*. Vol 7, 128-137, 1997.
52. Snyder A.C., K. Moorhead, J. Luedtke, M. Small. Carbohydrate consumption prior to repeated bouts of high intensity exercise. *Eur J Appl Physiol*. Vol 66, 141-145, 1993.
53. Sparks M.J., S.S. Selig, M.A. Febbraio. Pre-exercise carbohydrate ingestion: effect of the glycemic index on endurance exercise performance. *Med Sci Sports Ex*. Vol 30, 844-849, 1998.
54. Tsintzas K., C. Williams. Human Muscle Glycogen Metabolism during exercise. *Sports Med*. Vol 25, 7-23, 1998.
55. Thomas D.E., J.R. Brotherhood, J.B. Miller. Plasma glucose levels after prolonged strenuous exercise correlate inversely with glycemic response to food consumed before exercise. *Intl J Sports Nutri*. Vol 4, 361-373, 1994.

56. Utter A.C., J. Kang, D.C. Nieman, F. Williams, R.J. Robertson. Effect of carbohydrate ingestion and hormonal responses on ratings of perceived exertion during swimming and running. *Eur J Appl Physiol*. Vol 80, 92-99, 1999.
57. Wahren J., P. Felig, G. Ahlborg, L. Jorfeldt. Glucose metabolism during leg exercise in man. *J Clin Invest*. Vol 50, 2715-2725, 1971.
58. Wilber R.L., R.J. Moffatt. Influence of carbohydrate ingestion on blood glucose and performance in runners. *Intl J Sports Nutr*. Vol 2, 317-327, 1992.
59. Wouassi D., J. Mercier, S. Ahmaidi, J.F. Brun, B. Mercier. Metabolic and hormonal responses during repeated bouts of brief and intense exercise: effects of pre-exercise glucose ingestion. *Eur J Appl Physiol*. Vol 76, 197-202, 1997.
60. Wright D.A., W.M. Sherman, A.R. Dernbach. Carbohydrate feedings before, during or in combination improve cycling endurance performance. *J Appl Physiol*. Vol 71, 1082-1088, 1991.

APPENDIX A

Table 6. Individual Blood lactate values for each trial condition (mmol·L⁻¹)

	<u>Post ex 0 min</u>	<u>Post-ex 2min</u>	<u>Post-ex 4min</u>	<u>Post-ex 6min</u>
1	G5- 3.57 G35- 4.8 PL- 4.52	G5- 3.74 G35- 4.67 PL- 4.61	G5- 3.7 G35- 4.4 PL- 4.18	G5-3.36 G35- 4.27 PL- 3.87
2	G5- 2.6 G35- 2.06 PL- 2.9	G5- 2.37 G35- 2.04 PL-2.6	G5- 2.15 G35- 1.67 PL-2.0	G5- 2.07 G35- 1.4 PL-2.1
3	G5- 1.57 G35- 2.75 PL-2.06	G5- 1.3 G35- 2.62 PL-2.01	G5- 1.43 G35- 2.25 PL-1.81	G5- 1.4 G35- 2.71 PL-1.8
4	G5- 6.58 G35- 4.5 PL-2.43	G5- 6.2 G35- 3.9 PL-2.1	G5- 5.7 G35- 3.7 PL-2.0	G5- 5.7 G35- 3.9 PL-1.9
5	G5- 1.9 G35- 4.4 PL- 1.7	G5- 2.1 G35- 4.3 PL- 1.9	G5- 2.2 G35- 4.3 PL- 1.6	G5- 2.1 G35- ** PL- 1.6
6	G5- 2.0 G35- ** PL-2.1	G5- 3.0 G35- 2.6 PL- **	G5- 2.8 G35- 2.6 PL-3.0	G5- 2.2 G35- 2.7 PL-2.4
7	G5- 3.4 G35- 4.0 PL- 5.44	G5- 3.2 G35- 3.6 PL-3.2	G5- 3.1 G35- 3.3 PL-5.9	G5- 2.8 G35- 2.7 PL-5.6
8	G5- 2.9 G35- 3.1 PL-**	G5- 2.6 G35- 2.4 PL- 2.2	G5- 2.1 G35- 1.3 PL-**	G5- 1.8 G35- 1.4 PL- 2.0
9	G5- 3.5 G35- 4.2 PL- 3.4	G5- 2.9 G35- 3.0 PL-2.6	G5- 2.4 G35- 3.0 PL-2.4	G5- 2.0 G35- ** PL-2.9
10	G5- 4.0 G35- 5.8 PL- 3.7	G5- 3.9 G35- 5.2 PL-3.6	G5- 3.3 G35- 5.5 PL-3.5	G5- 2.8 G35- 4.9 PL- 3.6
$\bar{X} \pm SD$	G5- 3.2 $\pm$ 1.4 G35- 4.0 $\pm$ 1.1 PL- 3.3 $\pm$ 1.3	G5- 3.1 $\pm$ 1.3 G35- 3.4 $\pm$ 1.1 PL- 2.7 $\pm$ 1.0	G5- 2.9 $\pm$ 1.2 G35- 3.2 $\pm$ 1.3 PL- 2.9 $\pm$ 1.4	G5- 2.6 $\pm$ 1.2 G35- 3.2 $\pm$ 1.2 PL- 2.9 $\pm$ 1.3

** Denotes missing sample

Table 7. Individual blood glucose (mmol·L⁻¹) measures for each subject under all three trial conditions.

<u>Subject</u>	<u>5 Min Prior</u>	<u>0 min Post</u>	<u>5 min Post</u>	<u>10 Min Post</u>
1	G5- 4.7 G35- 6.2 PL- 4.8	G5- 5.6 G35- 6.8 PL- 5.8	G5-5.7 G35-7.7 PL-5.6	G5- 5.5 G35- 6.2 PL- 5.1
2	G5- 5.2 G35- 8.9 PL- 5.2	G5- 4.4 G35- 3.8 PL- 3.7	G5-4.9 G35- 4.0 PL-4.1	G5- 4.7 G35- 4.1 PL- 4.2
3	G5- 5.6 G35- 8.2 PL- 5.4	G5- 4.9 G35- 4.6 PL- 4.8	G5- 5.3 G35- 4.7 PL- 4.8	G5- 5.1 G35- 4.5 PL- 4.8
4	G5- 5.0 G35- 7.8 PL- 5.2	G5- 5.3 G35- 4.4 PL- 4.3	G5- 5.6 G35- 4.5 PL- 4.6	G5- 5.7 G35- 4.2 PL- 4.4
5	G5- 4.8 G35- 7.6 PL- 4.9	G5- 4.4 G35-5.6 PL- 4.9	G5- 5.1 G35- 5.7 PL- 4.9	G5- 4.4 G35- 4.9 PL- 4.6
6	G5- 4.8 G35- 8.0 PL- 4.7	G5- 3.2 G35- 3.2 PL- 4.3	G5- 3.6 G35- 4.0 PL- 4.3	G5- 3.9 G35- 4.1 PL- 4.4
7	G5-5.1 G35- 9.8 PL- 5.6	G5- 5.3 G35- 5.1 PL- 5.6	G5- 5.2 G35- 4.9 PL- 5.8	G5- 5.3 G35- 4.9 PL- 5.6
8	G5- 6.3 G35- 9.6 PL- 6.1	G5- 5.1 G35- 5.2 PL- 5.8	G5- 5.7 G35- 5.4 PL- 6.0	G5- 5.7 G35- 5.3 PL-5.8
9	G5- 5.1 G35- 8.4 PL- 5.3	G5- 5.6 G35- 5.3 PL- 4.7	G5- 5.6 G35- 5.2 PL- 5.0	G5- 5.4 G35- 5.1 PL- 4.8
10	G5- 5.8 G35- 9.1 PL- 5.8	G5- 6.8 G35- 6.6 PL- 6.0	G5- 6.8 G35- 6.4 PL- 6.0	G5- 6.6 G35- 6.0 PL- 5.7
$\bar{X} \pm SD$	G5- 5.2 $\pm$ 0.5 G35-8.4 $\pm$ 1.1 PL- 5.3 $\pm$ 0.4	G5- 5.1 $\pm$ 0.9 G35- 5.1 $\pm$ 1.1 PL- 5.0 $\pm$ 0.8	G5- 5.4 $\pm$ 0.8 G35- 5.3 $\pm$ 1.1 PL- 5.1 $\pm$ 0.7	G5- 5.2 $\pm$ 0.8 G35- 4.9 $\pm$ 0.7 PL- 4.9 $\pm$ 0.6

Table 8. Average heart rate (bpm) for each subject under each trial condition.

Heart rates listed are the average during the course of the entire trial.

Subject	G5	G35	PL
1	147.3	149	150
2	163.9	162.3	158.5
3	166.5	173.2	168.9
4	170.6	165.7	163.2
5	136.5	144.78	131.3
6	138.3	141.6	135.6
7	155.1	156.2	158
8	152.4	154.1	151.4
9	140.7	144.6	141
10	164.9	166.3	162.6
X / SD	153.6 $\pm$ 12.6 bpm	155.8 $\pm$ 10.8 bpm	152.1 $\pm$ 12.6 bpm

G5- Subject ingested glucose solution 5 minutes prior to exercise

G35- Subject ingested glucose solution 35 minutes prior to exercise

Placebo- Subject ingested an isocaloric solution prior to exercise.

Table 9. Individual Rating of Perceived Exertion for each trial condition taken at the end of the exercise period.

Subject	G5	G35	Placebo
1	15	15	15
2	14	14	15
3	16	15	16
4	14	14	15
5	15	17	15
6	14	15	15
7	13	13	13
8	14	13	13
9	15	16	14
10	15	16	15
X	14.5± 0.9	14.8± 1.3	14.6± 0.96

G5- Subject ingested glucose solution 5 minutes prior to exercise

G35- Subject ingested glucose solution 35 minutes prior to exercise

Placebo- Subject ingested an isocaloric solution prior to exercise.

Table 10. Individual Dietary content for 48 hours prior to each trial.

	G⁵	G³⁵	PI
	Total cal (kcal)	Total cal (kcal)	Total cal (kcal)
	Total carb (g)	Total carb (g)	Total carb (g)
1	5351 870	5499 880	5690 869
2	6094.00 922	6468.00 1022	6568.00 1046
3	4814.00 788	4404.00 713	4904.00 906
4	4768 879	4890 893	4954 910
5	6554 969	6203 922	6452 930
6	5261 904	5695 828	5452 882
7	6410 1018	6230 959	6567 994
8	**	**	**
9	5430 854	5101 803	5204 815
10	5789 889	5422 815	5526 852
Calories (kcal)	5607±648	5545±682	5701±670
CHO (g)	899±66	870±92	911±71

** Denotes missing sample

G5- Subject ingested glucose solution 5 minutes prior to exercise

G35- Subject ingested glucose solution 35 minutes prior to exercise

Placebo- Subject ingested an isocaloric solution prior to exercise.

Figure 3. Performance time difference (min) between glucose trials and placebo.