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Effects of Pre-Exercise Carbohydrate Consumption on Metabolism During Exercise

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Effects of Pre-Exercise Carbohydrate Consumption on Metabolism During Exercise

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Report

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Kinesiology

The University of Texas at Austin

May 2016

Acknowledgements

I'd like to thank Dr. Edward Coyle for allowing me to have this opportunity in his lab. His guidance and experience has assisted my development as an exercise scientist. He has guided me tremendously in becoming an independent researcher. Next, I'd like to thank my partners in the lab, Dongwoo Hahn, Jakob Allen, Michael Brenneman and Heath Burton. I'd like to especially thank Ting Chou and Brian Leary for the guidance as PhD students who helped me develop my lab skills. I want to say a large thank you to Dr. Stone in taking time out of her schedule to be my second reader. Lastly, I'd like to thank my wife Julia. Her care, support and companionship in navigating this report has meant the world to me. I am overwhelmed with joy and thankfulness for her to be in my life.

Abstract

Effects of Pre-Exercise Carbohydrate Consumption on Metabolism During Exercise

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It is well documented that consuming carbohydrates (CHO) prior to exercise has been shown to alter metabolism. There are many ways that CHO ingestion affects substrate utilization and blood glucose dynamics at the start of exercise. Changes in the concentrations of blood glucose, insulin, glucagon, free fatty acids (FFAs) as well as varying utilizations of different substrates have been observed. Each of these responses is reflective of the body's capacity to maintain homeostasis through different physiological conditions and demands.

PURPOSE: The aim is to deduce how varying amounts (approximately 0, 12.5, 25 and 50g for a 70 kg person) of pre-exercise sucrose ingestion effects metabolism including blood glucose concentration and fat oxidation during 30 minutes of moderate intense exercise.

METHODS: This will be a randomized crossover study. After the initial assessment of baseline data (VO_2peak), participants will be asked to perform four cycling trials at 50% of VO_2peak for 30 minutes. Forty-five minutes before each exercise trial, participants will consume 0, 12.5, 25 and 50g (for a 70kg person) of sucrose. VO_2 and VCO_2 will be collected for 15 minutes prior to exercise and for the entire 30 minutes of cycling. Blood glucose will be obtained through the finger prick method and collected directly prior to exercise, 5, 15 and 30 minutes into cycling. Heart rate and rate of perceived exertion will be measured every 5 minutes of exercise.

DISCUSSION:

It is speculated that a small dose (12.5g for a 70kg person) of pre-exercise sucrose consumption will be able to demonstrate a decline in blood glucose concentration during exercise with a step-wise reduction in fat oxidation. This dose response curve will display the sensitivity of metabolism to ingested sucrose.

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Introduction

It is well documented that consuming carbohydrates (CHO) prior to exercise has shown to alter metabolism (15, 24, 28). There are many ways that CHO ingestion affects substrate utilization and blood glucose dynamics at the start of exercise (10, 15, 51). Changes in blood glucose, insulin, glucagon, free fatty acids (FFAs) as well as varying utilizations of different substrates have been observed (2, 27, 28). Each of theses responses is reflective of the body's capacity to maintain homeostasis in terms of adenosine triphosphate (ATP) production through different physiological conditions and demands.

After ingestion of CHO, the uptake of glucose by the muscle, liver, brain and kidney may account for at least 90% of the ingested glucose load's ending location. The liver takes up approximately 25-35% of initial CHO load while the rest enters the systemic circulation (36). Plasma glucose regulation involves both hormonal and non-hormonal responses (18). One way to see the affects of different blood glucose levels is the use of the hyperinsulinemic glucose clamp technique. This holding constant of plasma insulin has shown some physiological dose responses as plasmas glucose concentrations change. In one occasion, plasma insulin was clamped with variable glucose infusion rates to sequentially lower target glucose concentrations. As blood glucose declines from everyday resting levels (~81 mg/dl with normal activities) insulin secretion was suppressed. When blood glucose declined further (~67 mg/dl) glucagon and epinephrine release were increased. Then as plasma glucose declined even further (~65 mg/dl and below) cortisol secretion increased (37, 43).

These are several ways the body is trying to maintain homeostasis to keep blood glucose concentration high for the brain to continue to get enough energy or ATP.

When CHO is ingested, and blood glucose levels increase and the body increases insulin output from the pancreas (31). Insulin is a very powerful hormone that binds to cells to allow glucose to enter the cell. Higher concentrations of plasma insulin yield a higher rate of disappearance (R_d) of blood glucose. Insulin does more than increases R_d of blood glucose; it also decreases the rate of appearance (R_a) plasma FFAs, glycerol R_a because it suppresses lipolysis in a dose response manner (10). These responses generally peak about 30 minutes after a meal with higher glycemic index (GI) foods (27) and higher amounts of CHO ingested (30) increasing the magnitude of these responses.

When CHO is ingested 45 minutes prior to exercise, blood glucose and insulin are still above basal fasted levels at the start of exercise. R_a of glucose into the blood is high from the splanchnic area while R_a of glucose to the blood from the liver has decreased (48). Within the first 20 minutes of exercise, plasma glucose drops below fasting levels due to the high blood glucose Rd (3, 13, 15). A high level of insulin combined with the contraction of large muscle mass is responsible for this large blood glucose R_d (34). After 20 min, blood glucose (27) and insulin (28) return to basal levels due to firstly, R_a of blood glucose from the liver increasing (50) and secondly, R_d of blood glucose decreasing, (28) both responding from the decline of plasma insulin concentration. If insulin is high at the start of exercise and its affects are

prolonged; glycerol, plasma FFA, lipolysis and fat oxidation are suppressed during exercise compared to the fasted state (28).

Yet, it remains uncertain to what extent theses same changes will appear with a smaller dose of CHO. It is not yet known how small of a dose of CHO will perturb the body's ability to maintain homeostasis. I propose a study is needed to examine how lower doses (12.5, 25 and 50g) of CHO change blood glucose concentrations and fat oxidation.

Purpose

The purpose of this report is to propose a study that will compare varying amounts (0, 12.5, 25 and 50 g) of pre-exercise CHO ingestion and the subsequent effects on metabolism including blood glucose concentration and fat oxidation during 30 min of moderate exercise. CHO will be given in the form of sucrose (i.e.; table sugar) and adjusting the dose relative to body weight (i.e.; 0, 0.18, 0.36, 0.71 grams/kg body weight). This amounts to CHO doses of 0, 12.5, 25 and 50 grams respectively for a 70 kg person. It is expected that a step-wise reduction in fat oxidation and blood glucose concentration as pre-exercise CHO consumption increases, will occur. The aim is to determine if even a small dose of CHO (i.e.; 12.5 g; 50 kcal) perturbs metabolism.

Review of Literature

It has long been known that carbohydrate ingestion (CHO; sugar or high glycemic foods) before exercise increases plasma insulin concentrations leading to the blunting of fat oxidation as well as a transient and harmless drop in blood glucose concentration during subsequent exercise (10, 13, 15). Typically, the dose of CHO has been 50 g (200 kcal) or more (2, 13, 15, 28). However, previous work has suggested that even a small increase of plasma insulin prior to exercise caused by a small amount (25g) of CHO ingestion may be sufficient to suppress fat oxidation and cause a transient decrease in blood glucose concentration during exercise (30).

Exercise performed in the post-prandial state has been show to reduce blood glucose concentration within the first 20 min., due to glucose R_d increasing (28). The increase of glucose R_d is due to increased muscle uptake (2) coupled with hyperinsulinemia (28) even while blood glucose R_a is increasing from the ingested CHO (7). The decrease in lipolysis during exercise, even to where it limits fat oxidation, is due to elevations in plasma insulin (28). It is not yet understood if a small amount of ingested CHO affects these blood glucose changes during exercise. However, no study has systematically varied the amount of CHO ingested prior to exercise to determine the lowest amount (dose) that reduces fat oxidation and blood glucose concentration. The focus of this review will be on the physiological dose responses of CHO ingestion on metabolism at rest and during moderate exercise.

Carbohydrate Ingestion Before Exercise

During an overnight fast, the liver is the main source of glucose production, even though there is a small contribution from the kidneys (20). As the fast is broken and CHO is ingested, it is released by the splanchnic area and systemic blood glucose R_a increases significantly and thus blood glucose concentration rises with peak insulin levels soon after. Because of insulin, blood glucose R_d peaks 90 min after ingestion (36). Exogenous CHO is the primary source of systemic blood glucose R_a increasing substantially. When CHO is ingested, blood glucose R_a from the liver decreases while blood glucose uptake by the liver increases in order to restore liver glycogen. At rest, the liver takes up more of the glucose load with higher CHO doses (8). Muscle, adipose tissue and the noninsulin-dependent tissue together account for the other two thirds of blood glucose R_d (36).

Forty-five minutes after CHO ingestion, when the body is still digesting the meal and insulin and blood glucose levels have not yet returned to the fasting level (27), once exercise starts and blood insulin concentration decreases, the liver adapts from postprandial glucose uptake to the production of glucose (54). The additive affect of blood glucose R_d by the increase in muscle uptake (2) coupled with hyperinsulinemia (28) tips the balance of blood glucose R_d higher then blood glucose R_a. This creates a short period of hypoglycemia, peaking around 20 minutes into exercise (27, 28) and according to Jentjens et al. this decrease of blood glucose concentration is not dose dependent (30). Then plasma glucose rises back up to fasted levels (27) while the splanchnic area is continually heavily supporting blood glucose

R_a from the time of ingestion until the ingested meal is fully digested, which if sedentary, could be as long as 4 hours (36).

There is also a change in substrate use when CHO is ingested prior to exercise (28). The elevation of insulin reduces lipolysis, which in turn decreased the rate of fat oxidation. The body uses more blood glucose (CHO) for fuel when more is available. However, the decrease in fat oxidation can't always be made up by an increase in energy expenditure derived from blood glucose; therefore, higher rates of muscle glycogen may be used along side higher rates of blood glucose (24). Hargreaves et al showed this during the first hour of exercise with interval training, but after the first hour of exercise, glycogen reduction was lower with CHO feedings (24). Another study showed muscle glycogen was conserved with CHO feeding when 200g of CHO were ingested before 40 minutes of leg exercise at 30% of maximal oxygen uptake (2). Glycogen accounted for 20% of carbohydrate burned when fed to 57% with the participants are fasted. Therefore, the amount of muscle glycogen used seems controversial when CHO is ingested before exercise.

Blood Glucose

The human body contains roughly 4g of blood glucose when systemic blood glucose concentrations are in between 80-100mg/dl, thus illustrating how remarkable the body is at holding euglycemia. Yet the body is susceptible to hypoglycemia and hyperglycemia with changes in metabolic function and food intake. When eating CHO, blood glucose R_a increases and blood glucose concentration peaks between 30 and 90 minutes after ingestion,

(53) with higher dose of CHO peaking later. Meyer et al. (36) found that systemic glucose R_a peaked at 60 minutes after ingestion while systemic glucose R_d peaked at 90 minutes after ingestion due to insulin. They saw that at 30 minutes after ingestion, R_a of exogenous CHO rose sharply, while R_a of hepatic glucose dropped and at this time, 77% of circulating glucose was accounted by the ingested glucose. Hepatic glucose release before ingestion averages around 8.34 umol/kg/min and after glucose ingestion it decreases an average 81%. This shows that only a little extra insulin, above fasted levels, is capable of reducing hepatic glucose output (22).

The liver plays an important role in maintenance of blood glucose. It releases glucose in the fasted state and takes in glucose after a meal. In doing so, the liver can supply an even amount of glucose to the body and most importantly to the brain. Hepatic gluconeogenesis and glycogenolysis are the two processes by which hepatic glucose is produced. In the fasted state, the major source of energy is free fatty acids (FFAs) but the body continues to consume glucose at rates of 8-10g/hour (9). Hepatic glycogenolysis (the breakdown of glycogen to glucose-6-phosphate) contributes substantially to the liver's glucose output after an overnight fast. Then as fasting continues, hepatic glycogenolysis decreases gradually until the liver's glycogen stores are almost completely exhausted after 48 hours (41). Gluconeogenesis, the production of glucose from pyruvate or lactate or leucine etc., also has a very important role in the production of glucose by the liver. It is estimated that 47-53% of glucose turnover by the liver is due to gluconeogenesis 12-16 hours into fasting (11).

A marked drop in arterial glucose has been found at the onset of leg exercise following a meal (34). The dose response of this drop is not yet completely understood. Direct measurement of leg exchange of substrates during light-intensity exercise showed that the drop is due to an increase in glucose uptake by the working muscle, (3) even though the return of arterial glucose concentration levels begin to increase after 20 min (27). Leg glucose uptake during exercise was on average 2-3 fold higher after glucose ingestion. The way that exercise and insulin stimulate GLUT-4 receptor, which transports glucose into the cell, has an additive of blood glucose R_d (31). The lower R_a of blood glucose by the liver at the onset of exercise is met by a drop in blood glucose even though, when CHO is ingested before exercise, total R_a of blood glucose has increased due to R_a of blood glucose from the splanchnic being higher then in the fasted state (34).

The drop in blood glucose at the onset of exercise, comes with a drop in plasma insulin that promotes and increases glucagon secretion from the pancreas that in turn binds to receptors on the liver and induces rapid glycogenolysis and glycogenolysis (54). Even with an estimated decrease of hepatic blood flow during exercise, there is an increase in hepatic glucose output as exercise progresses (49). During a light bicycle exercise for short duration (20-30 min), glucose output has been shown to increase by 50-100% by the liver, possibly by increased sympathetic drive (49).

Insulin

Insulin can be responsible for the maintenance or hindrance of postprandial glucose homeostasis (36). Blood glucose will reach much higher concentrations without insulin after a meal, yet insulin is a large factor in the hypoglycemia found during the first 20 minutes during exercise after a meal. At rest, insulin is responsible for the large systematic blood glucose R_d following a systematic increase in blood glucose R_a. There is an uptake of glucose from the liver, kidney and muscle. Blood glucose peaks 30 minutes after ingestion of CHO and insulin peaks soon after (53) along with the decrease in plasma glucagon. Glucagon supports hepatic glucose release and therefore when suppressed, down regulates hepatic glucose R_a. Inversely, higher levels of glucagon up regulate liver glucose output. During glucose infusion, it has been demonstrated that as arterial glucose increases, arterial insulin increases and splanchnic glucose release decreases (22). This shows that the inhibition of hepatic glucose production is associated with glucose infusion through large increments of insulin levels. Insulin acts directly on the liver by binding to hepatic insulin-signaling pathways. Small changes in portal insulin concentrations effectively regulate hepatic glycogenolysis (22). Hepatic glycogenolysis and gluconeogenesis show differential sensitivities to changes in insulin concentrations. Small changes in insulin can inhibit glycogenolysis where substantial increments in plasma insulin is required to inhibit gluconeogenesis (12). Insulin is the primary regulator of hepatic glucose production, even though basal glucagon levels support overnight fasted glucose output (50). Thus the dose response to CHO ingestion on insulin secretion also has an insulin response that minimizes or magnifies different physiological responses.

Insulin is also the driver of less fat oxidation after a meal. It regulates plasma FFA R_a by blunting lipolysis while maintaining a constant level of FFA re-esterification (10). When there are less FFAs entering the blood there is less FFAs concentration (27) along with less FFAs that are available to be used. Fewer FFAs make less Fatty-Acyl-CoA for the mitochondria to convert to ATP. The body's ability to inhibit lipolysis, and decrease fat oxidation, is very sensitive to insulin. Campbell et al. (10) infused insulin to show the dose response of lipolysis and FFA re-esterification. Higher amount of insulin caused a decrease in lipolysis but had no affect on the absolute rate of primary FFA re-esterification but it was shown that insulin regulates FFA R_a. Oral glucose may have different physiological dose affects then intravenously administered glucose or insulin, especially in smaller amounts. Even low elevations in plasma insulin will suppress lipolysis during exercise (28). Allen et al (5) demonstrated an explanation for these findings. The joining of insulin to a specific receptor is the first step in the blunting of lipolysis. Only a few of these receptors having insulin occupation is sufficient to prolong the fat oxidation blunting action that insulin has, even when the perfusion of insulin into the body has concluded (3).

At the start of postprandial exercise, the elevated plasma glucose and insulin increases the rate of CHO metabolism without a compensatory increase in plasma FFAs (13). After 30 minutes into exercise, insulin returns to a fasted level (27). But the changes in regulation of substrates can persist until the second hour of exercise, depending on the dose, even when plasma insulin has returned to the same levels of fasting prior to exercise (15).

Substrate Utilization

When we eat more CHO before exercise, there is a shift toward higher rates of CHO oxidation. Our body uses a combination of whatever substrate is more available and which substrate is easier to metabolize at moderate intensities. When introducing exogenous glucose to our body, glucose becomes an increasingly substantial source of fuel for the muscle while exercising, even without high insulin involved (49).

After higher doses of CHO ingestion, the augmented glucose uptake by the working muscle increases along with the blunting of fat oxidation. This happens when the insulin response to the higher blood glucose is raised (3). With the blunting of lipolysis, yielding to less calories derived from fat; sometimes blood glucose can't make up the difference in ATP needed, especially if there is an insufficient dose of CHO (28). Therefore, glycogen may make up the difference. On the other hand, a high dose of CHO may decrease the amount of muscle glycogen used during exercise (2, 33).

Coyle et al. demonstrated the reliance on CHO when in 1985 he fed cyclists 4 hours before exercise. He saw this reliance on CHO despite a return in blood glucose and plasma insulin back to normal concentrations prior to the start of exercise. These effects can last until the second hour of exercise (15). McConell et al. also showed that during 2 hours of cycling at about 70% VO2 peak, participants who ingested CHO before exercise had a significantly lower concentration of FFA and a higher concentration of insulin (34). As just previously

mentioned, this demonstrates the same substrate use after a meal that Coyle et al. did (15). One way these effects can be measured is through indirect calorimetry using respiratory exchange ratio (RER). RER is higher after a larger dose of glucose, (2) demonstrating a higher overall CHO oxidation and lower full body fat oxidation.

Glycemic Index

The glycemic index, which is a number based on the raise in blood glucose after eating a particular food, of the CHO ingested plays an important role in the response of the body. Higher glycemic CHO have systemic blood glucose concentrations for a longer period of time or a higher area under the curve. Glucose R_a into the blood can be from a high or low GI food (42). For example: Glucose elicits a higher blood glucose and insulin response and a higher RER then fructose (25, 33). Blood glucose and plasma insulin respond differently to meals based on how high or low the GI and how much fat and protein accompanies the CHO (27). Higher GI meals elicits higher plasma glucose responses with a lower concentration of plasma FAAs at rest (45). High GI meals also elicit a lower glycerol response and a higher degree of the suppression of fat oxidation and plasma FFA concentration, (28, 45) 20 minutes into exercise if CHO taken prior to the start of exercise. Yet, these responses to the meal have no difference in driving down plasma glucose to equally low concentrations early in exercise (27).

High and low GI CHO can produce different postprandial insulin responses depending on how different the GI is. When the area under the curve (AUC) was evaluated for 24-hour

insulin profiles, the high sucrose diet was found to produce an AUC for insulin similar to that produced by a high-starch diet (19). With the only major difference being sucrose had a higher insulin peak immediately after each meal. In the same study, it was shown that their high sucrose diet had a higher blood glucose concentration after each meal (except for breakfast) and continued to stay elevated above the blood glucose concentration of their high-starch diet until the next meal (19).

Wee et al. demonstrated that a higher GI meal prior to exercise increased plasma glucose and serum insulin response curves (51). They also showed that a higher GI meal increases muscle glycogen more than a low GI meal during a three-hour postprandial period without exercise. Yet, muscle glycogen utilization was higher once exercise commenced for those who ingested the high GI meal. Thus, the lower GI meal showed a sparing of muscle glycogen utilization during exercise, most likely because fat oxidation was higher (51). It is important to note the physiological changes to varying CHO meals based on its GI.

Response of Carbohydrates

Bratuschmarrain et al. (8) demonstrated seveal key aspects of different doses of CHO ingestion when looking for the best dose for an oral glucose tolerance test. They gave participants either 12.5, 25, 50, 75 or 100g of glucose. Illustrated previously, as the dose of ingested glucose went up, the amount of glucose R_a from the splachnic area and insulin response increased with it, with the highest increase of insulin concentration between 75 and 100g of ingested CHO. Yet glucose retention in the liver had a ceiling response of 50g of

glucose or higher demonstrating a similar percentage of ingested glucose that was retained in the liver. Glucagon was also suppressed throughout the observation period, with the lowest amounts being most marked in the trials with the highest CHO ingested (8).

Bratuschmarrain et al. also showed that splanchnic glucose output rate increases as the dose of CHO ingested increases. Yet, there was a plateau in relative splanchnic glucose retention (SGR) when glucose ingestion exceeded 50g. SGR never exceeded 80% of the amount of ingested glucose. Splanchnic tissue is the major site of glucose uptake for high glucose loads. Smaller amounts of glucose lead to larger amounts of glucose escaping the splanchnic circulation. When unraveling these results, it is key to understand that the amount of glucose released by the splanchnic bed incorporates the net result of the glucose load absorbed, as well as suppression of hepatic glucose production (8).

When a 100g dose was ingested, the liver retains most of it with peripheral tissues representing only a minor site of glucose utilization. It is apparent that the absolute amount of glucose taken up by the liver rises with the dose of glucose ingested and thereby with dose-dependent stimulation of insulin production. Thus, it will seem that large glucose loads facilitate hepatic glucose uptake by eliciting both the release of pancreatic insulin secretion and by hyperglycemia, whereas smaller loads do not (8).

Sucrose

During digestion, sucrose is broken down in to its constituent parts. This disaccharide, through the enzyme sucrase, becomes the monosaccharaides glucose and fructose. The resulting glucose and fructose molecules are then absorbed (23). Glucose has a high GI while fructose has a low GI and independently, at the same dose, they have vastly different effects, glucose perturbing metabolism more (28). But sucrose affects metabolism very similarly to glucose (46).

In a study done by Horowitz et al. (27), the intake of sucrose, potato (starch) or syrup plus fat caused a higher resting blood glucose and insulin response than rice, rice plus fat or potato plus fat when measured 30 minutes after ingestion. Twenty minutes into exercise, all blood glucose concentrations from all trials were similarly below fasted basal level and all rose back to the fasted basal level within 60 minutes into exercise. The ingestion of potato and sucrose were the only trials to exhibit a significant increase in the rate of CHO oxidation above control while cycling at 60% VO_2 max. (27).

When about 84g of CHO were ingested with equal amount of protein and fat in each meal while the composition of the CHO changed, sucrose had no different response then fructose, potato and glucose (4). Mean plasma concentrations of glucose and mean serum concentrations of insulin were evaluated for AUC in healthy subjects to the same levels. Yet peak increments in plasma glucose were highest for sucrose and glucose (6). These same results have also been demonstrated with sucrose and glucose ingestion compared to starch.

Where starch had a lower plasma glucose concentration, plasma insulin in AUC and peak levels of insulin concentration from sucrose and glucose were similar (46).

High Dose of Carbohydrates

There have been a number of studies that have looked at the affect of higher amounts of CHO load on the body during and before exercise (1, 4, 8, 10). Higher amount of CHO elicit higher levels of plasma insulin, but there seems to be a maximal dose response where even 75g and 200g of CHO elicit the same plasma insulin response (30). The effects that insulin has on blunting lipolysis can last far longer than the appearance of elevated plasma insulin. Consuming 2g CHO per kg body weight of CHO can blunt fat oxidation for 8 hours, even when plasma insulin returned to fasting level 4 hours after eating (38).

The dose response of glucose, lipolysis and FFA dynamics when ingesting 150g compared to 75g of CHO 90 minutes prior to exercise, blunts lipolysis to a greater extent. Both had similar drops in plasma glucose at the start of exercise as well as similar decrees in insulin and similar reduction in FFA response compared to the fasted state (44).

Ahlborg et al. demonstrated that 200g of CHO ingestion 50 minutes prior to exercise elicited a 2-3 fold higher leg glucose uptake which accompanied about a 20% increase in carbohydrate oxidation 20 minutes into exercise (2). Coyle et al. (15) demonstrated that 140g of CHO and 21g of protein 4 hours prior to exercise elicited a rise in both plasma insulin and blood glucose, but both fell back to fasted levels before exercise. In the first 20 minutes of

exercise: plasma insulin was not different yet blood glucose was lower, FFA was lower, glycerol was lower and RER was higher compared to the fasting trials (15). This equated to a 50% increase in carbohydrate oxidation in the CHO fed group 12 minutes into exercise.

Low Dose of Carbohydrates

Historically studies on CHO ingestion prior to exercise have focused on 50g (200 calories) or more of CHO (2, 6, 38, 51). One study showed that 25g of CHO 45 minutes prior to exercise is enough to elicit a decrease in plasma glucose and an increase in plasma insulin (22). Yet, RER was the same for 25, 75, 200g doses of CHO since intensity was too high (72% Vo_2 peak), it dictated substrate use (30) over pre-exercise meal composition. Comparatively to other studies that observed a decrease of blood glucose concentration at the onset of exercise with a 2g/kg body weight of CHO four (15, 27) and or two hours (38) between eating and the start of exercise while Levine et al. did not show the same hypoglycemia with ingesting CHO, 75g, 45 min before exercise (33).

Bratuschmarrain et al. (8) demonstrated that at rest 12.5 and 25g of glucose resulted in a moderate increase in insulin and moderate decrease in glucagon. These doses were responsible for splanchnic glucose output approximately doubling above basal levels within 15 to 30 minutes compared to groups ingesting 75 or 100g of glucose having a 5-fold increase. He also showed that 12.5g of glucose ingestion has a markedly lower percent of its glucose retained by the hepatic region associated with a lower amount of insulin. These lower doses of CHO do have a metobolic affect on the body(8).

Integrative Outlook

Following ingestion of CHO, systematic blood glucose concentration increases with the rise in insulin closely behind (36). High insulin levels decrease glucagon in the blood and the liver decreases its contribution to blood glucose R_a and increases its uptake of glucose to restore its glycogen. The large R_a of glucose into the blood by the splanchnic region is due to the exogenous CHO intake of larger doses.

At the start of exercise, when blood glucose concentration and plasma insulin are still high above fasted basal levels, there is a large decrease in blood glucose concentration within the first 20 minutes (27). This is primarily due to the additive glucose R_d by the working muscles contracting (2) and high insulin in the blood (24). At the fall of plasma insulin concentration, the liver quickly switches from intake to output of glucose to help meet the demands of exercise (54). After 20 minutes, this exercise induced hypoglycemica starts to diminish. This change is two fold; as plasma insulin levels decline, blood glucose R_d declines and (21) hepatic glucose production increases (54). Thus, blood glucose levels rise back to levels closer to those found in the fasted state, in euglycemia.

Many studies have demonstrated the physiological responses to higher (50g or greater) amounts of CHO intake and Bratuschmarrian et al. (8) was able to demonstrate how lower levels of CHO ingestion have physiological affects at rest. Jentjens et al. (30) suggested that even a small increase of plasma insulin prior to exercise caused by a small dose (25 g) of CHO ingestion may be sufficient to suppress fat oxidation and cause a transient decrease in

blood glucose concentration during exercise, but it is not yet completely understood how smaller amounts, or what is the smallest amount, of CHO that changes metabolism during moderate intensity exercise.

Proposal: Effects of Pre-Exercise Carbohydrate Consumption on Metabolism During Exercise

I propose that there will be a dose response with smaller amounts of ingested CHO on metabolism. CHO ingestion prior to exercise will result in a transient drop in blood glucose at the start of exercise, an increase in CHO oxidation and a blunting of fat oxidation. These results will be associated with higher blood glucose and insulin levels after feeding. The aim will be to demonstrate these relationships with a minimal amount of CHO prior to exercise.

Proposed Study Design

The purpose of this study will be to compare varying amounts (0, 12.5, 25 and 50 g) of pre-exercise CHO ingestion and the subsequent effects on metabolism including blood glucose concentration and fat oxidation during 30 minutes of moderate exercise. We will be administering the CHO in the form of sucrose (i.e.; table sugar) and adjusting the dose relative to body weight (i.e.; 0, 0.18, 0.36, 0.71 grams/kg body weight). This amounts to CHO doses of 0, 12.5, 25 and 50 grams respectively for a 70 kg person. We expect to find a step-wise reduction in fat oxidation and blood glucose concentration as pre-exercise CHO consumption increases and I aim to determine if even a small dose of CHO (i.e.; 12.5 g; 50 kcal) perturbs metabolism.

Experimental Approach

1. Overview of Initial Screening.
2. Informed consent will be obtained.
3. Health Questionnaire and Physical Activity Questionnaire will be completed if individuals are eligible to participate.
4. Familiarization period with equipment by performing an oxygen consumption (VO_2) submaximal and peak VO_2 test while cycling.
5. Four experimental trials with 0, 12.5, 25 or 50 g of CHO ingested (for a 70kg person) in a randomized order 45 minutes before exercise.
6. Cycle for 30 minutes at 50% VO_2peak with the following measures at times 0, 5, 15 and 30 minutes: respiratory exchange ratio (RER), blood glucose concentration, Heart rate (HR) and rating of perceived exertion.

Proposed Protocol

1. Visit 1 will last approximately 90 minutes.
    I. Informed consent will be obtained.
    II. Health Questionnaire and Physical Activity Questionnaire will be completed if individuals are eligible to participate.
        1. At this time inclusion/exclusion will be determined based off of the responses to the Health Questionnaire and Physical Activity Questionnaire.

III. Body mass will be measured to the nearest 0.01 kg with a digital scale (LifeSource, UC-321, A&D Medical, San Jose, CA)

IV. Familiarization period with equipment by performing a VO_2 submaximal and peak VO_2 test while cycling.

2. Visits 2 through 5 will last approximately 100 minutes.

I. Tweny-four hours prior to testing, participants must eat an identical diet, ingested no caffeine or alcohol, have not exercised and be at least 12 hours fasted.

II. Body mass will be measured to the nearest 0.01 kg with a digital scale (LifeSource, UC-321, A&D Medical, San Jose, CA)

III. Participants will ingest 0, 12.5, 25 or 50g of sucrose in a randomized fashion (for a 70kg person).

1. Ingestion will occur while seated and participants will remain seated for 45 minutes, until exercise starts.

IV. Each trial will consist of 15 minutes of resting gas exchange 25 minutes after ingestion and 30 minutes of cycling at 50% VO_2 peak, 45 minutes after ingestion.

1. RER will be recorded during the 15 minutes of rest and 30 minutes of cycling.
2. Blood glucose will be obtained through finger pricks during cycling at time 0, 5, 15 and 30 minutes of each bout of exercise.

3. RPE will be asked of participants every 5 minutes of exercise by showing the scale and verbally asking.
4. HR will be recorded immediately prior to exercise and every 5 minutes during exercise.
5. All trials will be performed at least 3 days apart.

Participants

a. Target Population:

Twelve moderately healthy men and women between the ages of 18 and 40 years old will be recruited for this study.

b. Conditions to end participation

Participants will end their involvement in this study if they become injured, cannot perform required exercise or protocol to expected levels, if they request to stop or if it becomes unsafe for them to continue.

c. Exclusions

We will exclude: trained athletes, diabetics, the injured, those who are taking cardiovascular-acting drugs or have present cardiovascular risk factors, women who are pregnant.

d. Benefits:

Each subject completing the study will be provided with information about his or her VO_2 peak, which is useful to running and bicycling training and performance. This information will be given to them at no cost where it could cost $100 at local health club facilities.

e. Risks:

The fatigue test to measure VO_2 peak will feel uncomfortable due to high heart rate, high respiration rate and the exertion of the working muscles. There is a very small risk the participant could experience a muscular injury, such as a muscle strain. There is the very remote possibility, as with any type of intense exercise in a person with undiagnosed heart disease, of a heart attack. During the tests, they may stop performing the task at any time for any reason if they feel they need to do so. However, the exercise intensities are individually controlled in accordance with their first visit. If they have a sugar allergy or sensitivity, ingesting sugar could cause fatigue, joint pain, stomach discomfort, allergy rash and cramps. However the average American diet has more sugar in it daily then they will be ingesting. At any point they may stop their participation in this study.

Risks associated with finger prick for blood glucose concentration are the discomfort associated with prick and, risk of infection (<1 in 1000). To minimize infection risk, only new and sterile lances will be used and the area will be wiped

with an alcohol swab both immediately before and after administering the finger prick.

Measurements

a. Body Mass Measurement

Subjects will have their body mass determined by standing on a digital scale (LifeSource, UC-321, A&D Medical, San Jose, CA) and body mass will be measured to the nearest 0.01kg. This information will be used to give the correct dose of sucrose for each participant based off body weight.

b. Rate of Perceived Exertion:

The Borg Scale will be used to ask the participant's RPE. It will be shown on a chart with the scale from 6-20 with descriptions to help the participants gage their difficulty.

c. Heart Rate:

Heart rate will be measured continuously from a strap worn around their chest (Suunto, Vantaa, Finland).

d. Blood Glucose Concentration:

Blood Glucose concentration will be measured by finger prick. The site will be cleaned (single use alcohol prep wipe), first drop of blood wiped away and second

analyzed (ONETOUCH Ultra 2 Glucose meter and ONETOUCH ultra Blue test strips, Lifescan Inc., Pilpitas, CA). Measurements will be made at 0, 5, 15 and 30 minutes of exercise.

e. Gas analysis (VO_2 and RER):

Using a facemask, gas exchange with oxygen and carbon dioxide analyzers will be measured (Applied Electrochemisty, Models S-3A/I and CD-3A, Respectively) while the participants breathe through a one-way valve (Hans Rudolph, Kansas City, MO). Ventilation will be measured via an inspiratory pneumotachometer (Hans Rudolph, Kansas City, MO). From this we will determine their oxygen consumption and identify their values (VO_2 and RER). Computer analysis will be done by MOXIS software.

f. Submaximal VO_2 and Peak Oxygen Consumption (VO_2 peak):

During this procedure, subjects will breathe into a facemask that will measure the O_2 and CO_2 concentration of expired air for calculation of their oxygen consumption (VO_2). The submaximal test will consist of 4 different stages, each being 5-minutes long to identify their VO_2 at the 50% level. During the test to determine VO_2peak, the intensity of exercise will be increased every 1-2 minutes until they are at their maximal effort level and become fatigued. This typically takes 6-10 minutes with the first 4 minutes are easy and the last 2 minutes are hard. Fatigue is associated with a difficulty or inability to maintain the exercise

speed (i.e.; reduced cadence when cycling). This duration and intensity of exercise is routinely experienced in cardiovascular training. These procedures are outlined in detail in publications cited (14, 16, 17, 47)

Discussion

The present study proposal was designed to speculate on the effects of lower amounts of carbohydrate consumption prior to exercise on metabolism and blood glucose dynamics during moderately intense exercise. I expect to find that that 12.5g of ingested CHO could be enough to decrease fat oxidation at rest and during exercise and that blood glucose concentration will decline during postprandial exercise when subjects consumed 12.5g or more of CHO. I expect to show blood glucose concentration declining during exercise and a step-wise reduction in fat oxidation and with even a small dose of pre-exercise CHO consumption demonstrating that it perturbs metabolism.

The drop in fat oxidation that I expect to show will most likely be due to a decrease in lipolysis from an increase in insulin (28, 39). One study showed that 12.5g, 25g and 50g of glucose produce an insulin level of (with baseline of 11 ± 2) 16 ± 2, 32 ± 7 and 70 ± 19 μU/mL at 45 minutes respectively (8) during an oral glucose tolerance test. Based off of the data from a study done by Meek et al., insulin levels of 11, 16, 32 and 70 μU/mL will inversely correlate to a decrease in lipolysis including a decrease in arterial FFA concentration of 148 ± 19, 44 ± 17, 19 ± 4 and 9 ± 1 μmol/L with a systemic flux of FFA of 115 ± 21, 38 ± 12, 21 ± 4 and 12 ± 2 μmol/min respectively (35). Since, it is well documented that the reduction in mobilization of FFA from the adipose tissue limits fat oxidation (10, 28, 40), it can be deducted that 12.5g of CHO will cause a suppression of

fat oxidation through an increase in plasma insulin by the blunting of lipolysis. These findings will demonstrate the sensitivity of substrate metabolism to CHO ingestion.

I speculate that 12.5g of CHO could decrease fat oxidation by a higher percentage at rest then during exercise. This large difference in the percentage of fat oxidation decreasing between rest and exercise will be most likely due to the plasma FFA R_a and plasma FFA concentration differences. At rest, plasma FFA concentration is lower than during moderate exercise (4). The percent of FFA oxidation contributing to total energy expenditure at rest is higher than during exercise due to lower total caloric demands. During moderate exercise, total FFA R_a is higher than at rest (26) due to an increased demand in energy with an increase in net substrate by the triglyceride fatty acid cycle (52). Therefore, I deduct that that the largest absolute rates of total fat oxidation will occur during exercise for this study. When participants were fasted while exercising at a moderate intensity and plasma insulin concentrations were at basal levels (<10 μU/ml), lipolysis was shown to be above fat oxidation (28, 52) and when there was higher plasma FFA concentration, total fat oxidation was also increased (13). Therefore, when plasma FFA makes up a larger percentage of substrate oxidation at rest then during exercise, a reduction in plasma FFA will have a larger overall affect on total substrate oxidation.

When a small dose of CHO is ingested and insulin is secreted, there is a reduction in lipolysis to where it falls below the rate of fat oxidation (28). A reduction in fat oxidation by means of a reduction in lipolysis was demonstrated by Horowitz et al. by increased fat

oxidation by 30% through an increase in lipolysis via intralipid and heparin infusion after glucose ingestion (28). However, this rise in lipolysis did not reestablish fat oxidation back to a fasting level implying that CHO consumption effects fat oxidation in other ways. Therefore, we will not be able to say that the reduction in lipolysis is completely explained by the drop in fat oxidation with low doses of CHO ingestion.

Another part of this study will be to demonstrate a step-wise reduction in blood glucose concentration with lower doses of CHO. This study will confirm the same trends as other studies (30, 44). I suspect that all CHO trials at baseline will have a blood glucose concentration above fasted level, but will the 12.5g trials be enough CHO to induce enough insulin to create hypoglycemia? One reason for it not to be enough CHO will be similar to the explanation for the difference in a decreased percentage of plasma FFA oxidation between rest and exercise conditions. Blood glucose is oxidized at higher rates and glucose production is higher through gluconeogenesis and glycolysis in the liver during exercise (48, 49). Therefore the 12.5g of exogenous CHO contributing to glucose R_a during exercise will have a lower relative contribution to overall blood glucose R_a then at rest. Then again, perhaps through oral glucose, our bodies are that sensitive to insulin and the rate of glucose coming out of the blood will be high enough.

The response of blood glucose concentration during exercise after CHO consumption will be due to several factors: the combination of insulin and muscle contraction on muscle glucose uptake and the level of plasma insulin, glucagon and catecholamine's effects on

liver glucose output and splachnic glucose retention (32, 54). The existence of hypoglycemia shortly into exercise does not appear to be correlated to insulin sensitivity (29) or the intensity of exercise (1).

In summary, this report is to propose a study that could test whether 12.5g of CHO ingested 45 minutes before exercise could be enough to decrease fat metabolism but not enough to induce hypoglycemia. I speculate that 25g or more of CHO will elicit hypoglycemia shortly into exercise. These low doses will also show a step-wise increase in RER, reduction of fat oxidation and decline in blood glucose concentration that will be inversely dependent on the relative amount of CHO consumed prior to exercise. This dose response curve will display the sensitivity of metabolism to ingested CHO.

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