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THE EFFECT OF EXERCISE ON GLYCEMIC AND INSULINEMIC RESPONSE TO TWO BEVERAGES OF DIFFERING GLYCEMIC INDEX

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Abstract

Introduction: The purpose of this study was to compare the glycemic and insulinemic responses of two beverages with differing glycemic index (GI) ingested immediately prior to exercise and at-rest.

Materials and methods: Nine trained male cyclists (Mean ± SD age 28.8±8.9 y, weight 76.5±4.0 kg and $\dot{V}O_2$max 57.6±5.7 mL·kg^{-1}·min^{-1}) each performed four randomised crossover treatment trials. A High (78) or Low (43) GI beverage was ingested either immediately prior to 110 min of (70% $\dot{V}O_2$max) cycling or at-rest.

Results: Exercise decreased blood glucose during the initial 60 min after the consumption of both LGI and HGI beverages ($P < 0.001$). There was a significantly greater blood glucose response with HGI than with LGI ($P < 0.02$) regardless of whether the beverages were consumed at-rest or prior to exercise, and a significant interaction between exercise and GI on blood glucose response ($P < 0.01$). The high variability in insulin response between participants precluded the detection of significant differences in insulin concentrations between any of the trials.

Conclusions: Cycling lowers the blood glucose response to both high and low GI beverages. This effect is more pronounced after ingesting a high GI beverage.

Key words: *glycemic index, blood glucose, insulin response, exercise, carbohydrate*

Introduction

Ingestion of carbohydrate (CHO) before and during prolonged exercise has been shown to maintain power output, and increase time to fatigue (1-5). This effect is attributed to the maintenance of both normal blood glucose concentrations and the rate of CHO oxidation (6, 7).

The Glycemic Index (GI) is used to rank CHO containing foods according to their glycemic response compared to a glucose reference and is measured in participants at rest (8). Foods with a high GI value cause a higher blood glucose and insulin response compared to foods with a low GI (9).

The vast majority of research conducted into the effects of high and low GI CHO consumed prior to exercise reported that the consumption of low GI CHO improved maintenance of blood glucose during exercise compared to high GI CHO (10-12). However, all of these studies have fed participants at least 45 min prior to exercise. Additionally, many of these studies have fed meals or solid foods to participants, which may not be convenient or appropriate for athletes wanting to consume CHO immediately prior to exercise, due to resulting gastrointestinal upset.

The feeding of CHO prior to exercise can be a contentious issue, mainly because some individuals are sensitive to the symptoms of hypoglycaemia which may affect sports performance. However, it has been reported that feeding CHO during a pre-competition or training warm-up, performed 1-2 hours after a meal, can eliminate the occurrence of hypoglyecmia (13).

The effects on blood glucose and insulin concentrations caused by feeding high and low GI CHO immediately prior to exercise (but after a warm-up) have not been investigated, nor have these responses been compared to the response to the same GI CHO consumed at rest. This may be important to athletes who train and compete early in the morning, and may want to eat immediately prior to exercise, rather than getting up an hour before exercise to consume CHO. Therefore, the aim of this study was to compare the glycemic and insulinemic responses of two beverages with differing GI ingested immediately prior to steady state exercise (but after a 10 min warm-up) and at-rest.

Materials and methods

Study Design

Each participant was involved in a preliminary testing session and four experimental trials. In the preliminary testing session $\dot{V}O_2$max was determined, and a one-hour sub-maximal exercise test was conducted to estimate sweat loss. The four experimental trials were performed using a randomised, crossover design. In the two exercise trials, either the high (HGI) or low GI (LGI) beverage was consumed after a 10-min warm up, but before 110 min of (70% $\dot{V}O_2$max) cycling. In the other two trials the beverages were consumed without any exercise (at-rest).

Participants

Nine male, endurance-trained cyclists participated in this study, all of whom cycled for at least 10 h a week. Their mean (± SD) age, height, weight and maximal aerobic capacity ($\dot{V}O_2max$) were 28.8 ± 8.9 years, 179.8 ± 6.4 cm, 76.5 ± 4.0 kg and 57.6 ± 5.7 $mL \cdot kg^{-1} \cdot min^{-1}$ respectively. The University Ethics Committee approved this study and all participants gave written informed consent.

Preliminary Testing

Height, and body mass measurements were made from all participants using standardised methods. Body mass was measured to the nearest 0.1 kg using portable electronic scales (Seca, Hamburg, Germany). Height was measured to the nearest 0.1 cm using a portable calibrated, self-made stadiometer.

An electromagnetically braked cycle ergometer (Velotron, Racermate inc., Seattle, USA) was used to determine $\dot{V}O_2max$. Participants were asked to maintain a pedal frequency of 90-110 rpm, first through a 5 min warm-up at 100 Watts, and then throughout the test, which began with a workload of 150 Watts. This workload was increased by 50 Watts every 2.5 min, until heart rate exceeded 165 bpm, at which time incremental steps were reduced to 25 Watts. The test continued until the participant could no longer maintain pedal frequency at the prescribed workload. Breath-by-breath analysis was performed throughout the test using an automated gas analysis system (Metalyser 3B, Cortex, Leipzig, Germany) and heart rate was measured using a radiotelemetry heart rate monitor (Polar Vantage NV, Kempele, Finland). Room temperature and humidity for both the $\dot{V}O_2max$ test and the subsequent hour of cycling were kept at approximately 20°C and 40%, respectively.

Within 10 min of completing the $\dot{V}O_2max$ test, participants were required to wipe themselves dry of sweat, and body weight (without clothes) was recorded. Participants then cycled at a power corresponding to 70% of $\dot{V}O_2max$ for one hour to estimate sweat loss. During cycling participants were allowed to drink *ad libitum* and the volume consumed was monitored. Sweat loss per hour was estimated by adding the weight of ingested water to the participants weight loss over the hour. The calculated sweat loss was then used to determine the amount of water given to the participant in the two experimental trials in which exercise was performed.

High and Low GI Beverages

Both the HGI (Gatorade® Thirst Quencher) and LGI (Sustagen® Sport) beverages contained 50 g of available CHO and were made up to a volume of 800 mL, to give a 6% CHO solution. Because one of the aims of this study was to use beverages in forms that are readily available to athletes, matching for energy and other macronutrients was not possible. Complete nutritional information of the beverages is presented in Table 1.

Table 1. *Nutritional information of the beverages*

	Low GI (Sustagen Sport)	High GI (Gatorade)
Flavour	Chocolate	Orange
Quantity	800 mL (76.57 g powder)	800 mL (55.56 g powder)
Energy	1198.0 kJ	873.0 kJ
Carbohydrate	50.0 g	50.0 g
Protein	19.0 g	0 g
Fat	0.8 g	0 g
Glycemic Index	43	78

Testing Protocol

All participants were asked to complete a food and activity record the day before the first trial and were then asked to replicate this food and activity pattern before the following three testing sessions. For 24 h before each testing session participants were instructed to avoid strenuous exercise. Participants were instructed to fast overnight for at least eight hours prior to each testing day, but were allowed to drink water *ad libitum* over this period. Meticulous standardisation procedures were not carried out as strict standardisation of exercise and dietary patterns prior to exercise testing has not been shown to decrease within subject variability (14). On testing days, participants reported to the laboratory at 0700 h to receive a standardised breakfast of low-moderate GI. This was done to standarize food intake, and the effect different nutrients may have on both insulin and glucose response. Breakfast consisted of two slices of mixed grain bread spread with one tablespoon of strawberry jam and a protein drink (Complan® Positiv™) consisting of 1 sachet of instant mix, mixed with 200 mL of water. The breakfast provided 1676.3 kJ of energy, of which 71% was provided from CHO, 21% from protein, and 8% from fat. The GI of the breakfast was calculated to be 56, using the method described by Wolever and Jenkins (15), GI values taken from Atkinson et al. (16) and unpublished values from the authors' laboratory. Over the following three hours participants attended class or work and were asked to avoid physical exertion and not to eat or drink before returning to the laboratory.

At 1030 h participants reported back to the laboratory to prepare for the experimental trial. To mimic a normal exercise session as closely as possible, all exercise trials were performed on the participants' own bicycles, attached to a computerised trainer (Kingcycle®, Bucks, UK). Participants performed a 10-min warm-up, at 50% $\dot{V}O_2$max before consuming one of the beverages. This warm-up was included in the study design as the consumption of CHO after a warm-up, but prior to the bout of exercise, has been shown to minimise the risk of a hypoglycaemic episode (13). Following consumption of the beverage, participants cycled at a workload corresponding to 70% $\dot{V}O_2$max for 110 min. Participants received equal volumes of water at 30, 45, 60, 75, 90 and 105 min after ingesting the beverage. The total volume of water each participant received per hour was equal to that lost during the one hour of cycling at the same intensity, in the preliminary trials. During the rest sessions, participant were asked to stay as immobile as possible for the entire 125 min. These sessions followed the same blood sampling protocol except that no water was consumed.

Sample Collection and Analysis

Blood samples were taken before breakfast (fasting), before the warm-up, before ingesting the beverage and at 15, 30, 45, 60, 90, 120 and 125 min after beginning to ingest the beverage. To ensure good blood flow to the fingertips during exercise and at-rest, participants were given a hot wheat bag prior to the finger prick blood samples. Only blood glucose was measured in the fasting sample prior to breakfast and the sample before the warm-up. At all other time points both insulin and blood glucose were measured. When a blood sample was taken during exercise the participants were required to stop cycling briefly while the sample was collected. A disposable finger lancet (Tenderlett®, Edison, USA) was used to collect the sample and blood glucose was measured with an automated blood glucose monitor (Hemocue Glucose 201+, Hemocue AB, Angelholm, Sweden). The within run and between day coefficient of variation were 3.7% and 2.5% respectively. For insulin analyses, approximately 1 ml of blood was collected in an Eppendorf tube (Sorenson™ Bioscience, Utah, USA). This blood was left to clot at room temperature for approximately 30 min, before being centrifuged at 3000 rpm for 10 min (Biofuge A, Heraeus Christ, Osterode, Germany). A minimum of 200 μL of serum was separated from the blood and stored at -80°C until analysis. Serum insulin was measured using a solid-phase ^{125}I radioimmunoassay (Coat-A-Count® insulin kit; Diagnostic Products Corporation, Los Angeles, USA).

Statistical Analysis

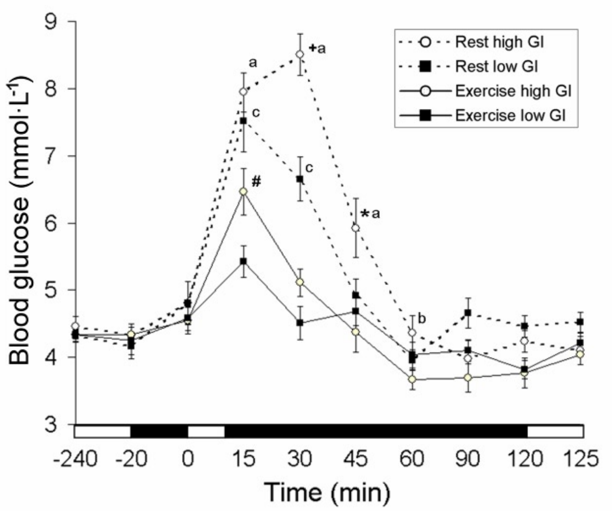
Statistical analyses were performed using SPSS (version 11.0.1) software. Insulin data were log transformed to correct for skew before inferential statistics were performed. The blood glucose and insulin data from the four trials were compared using a three-factor (time, beverage and exercise) ANOVA for repeated measures. Heart rate was used as an internal control for exercise intensity, and heart rates between the two beverage trials performed with exercise were compared using a two-factor (time and beverage) ANOVA for repeated measures. Differences in weight change and volume of water ingested for these trials were analysed with a paired-sample t-test.

Results

Body mass change, volume of ingested water and heart rate were not significantly different between the two exercise trials or between the two rest trials.

Blood Glucose Response

There were no differences between trials in blood glucose concentrations before breakfast (fasting), before the warm-up, or before ingesting beverages (Fig. 1).



Significantly different from LGI during exercise (P<0.05)
+ Significantly different from LGI at rest (P<0.001)
* Significantly different from LGI at rest (P<0.05)
a Significantly different from exercise after high GI (P<0.005)
b Significantly different from exercise after high GI (P<0.05)
c significantly different from exercise after low GI (P<0.001)

Fig. 1. *Mean ± SD Blood glucose concentrations (mmol·L^{-1}) for nine endurance trained cyclists, after ingestion of a low GI or high GI beverage during exercise and at rest*

Exercise trials

During the exercise trials the blood glucose response to both the HGI and LGI beverages peaked at 15 min after ingestion, although the blood glucose response to the HGI beverage was greater than the LGI beverage at this time point (P<0.05). Blood glucose concentrations were not different at any other time point during the exercise trials (Fig. 1). The mean (± standard error) blood glucose AUC for the LGI beverage was 12.8±5.0 mmol·L^{-1}·120 min^{-1}, and for the HGI beverage was 36.4±7.2 mmol·L^{-1}·120 min^{-1}.

Rest trials

At rest, the blood glucose response to the HGI and LGI beverages was similar 15 min after ingestion. However, after this time-point, blood glucose concentrations declined in response to the LGI beverage, while blood glucose concentrations continued to increase in response to the HGI beverage, and peaked at 30 min after consumption. At 30 and 45 min after ingestion, the blood glucose response to the HGI beverage was higher than that of the LGI beverage ($P<0.001$ and $P<0.05$, respectively) (Fig. 1). The mean (± standard error) blood glucose AUC for the LGI beverage was 70.9±6.5 mmol·L^{-1}·120 min^{-1}, and for the HGI beverage was 116.6±17.3 mmol·L^{-1}·120 min^{-1}.

Exercise vs Rest

During exercise the blood glucose response to both beverages was significantly lower than at rest at 15 and 30 min after ingestion ($P<0.005$ for HGI, and $P<0.001$ for LGI), but at 45 min only the blood glucose response to the HGI beverage was lower than it was at rest ($P<0.005$). Blood glucose concentrations had returned to baseline by 60 min after ingestion in all four trials (Fig. 1).

Overall, during the initial 60 min the blood glucose concentration was significantly higher in the resting trials ($P<0.001$) than in the exercising trials, and was significantly higher in the HGI trials than in the LGI trials ($P=0.02$). There was also a significant exercise and beverage interaction ($P=0.01$), which meant that exercise decreased blood glucose to a greater extent in the HGI trial than in the LGI trial. The increase in blood glucose concentration from 120 min after ingestion to 5 min following cessation of exercise (125 min after ingestion) was significantly greater ($P<0.05$) in the exercise trials than in the rest trials for both beverages.

Insulin Response

There was no significant effect of either beverage or exercise on serum insulin concentration (Fig. 2). There was, however, large variability in the insulin responses (Fig. 2). Ingestion of the HGI beverage resulted in blood glucose and insulin concentrations

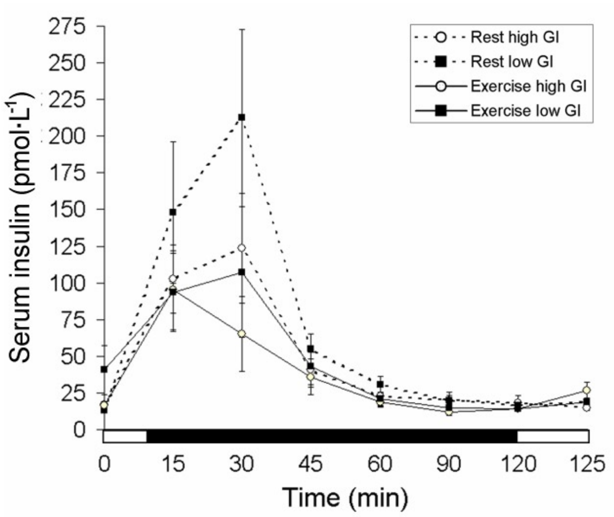


Fig. 2. *Mean ± SD Serum Insulin Concentrations (pmol·L^{-1}) for nine endurance trained cyclists after ingestion of a low GI or high GI beverage during exercise and at rest*

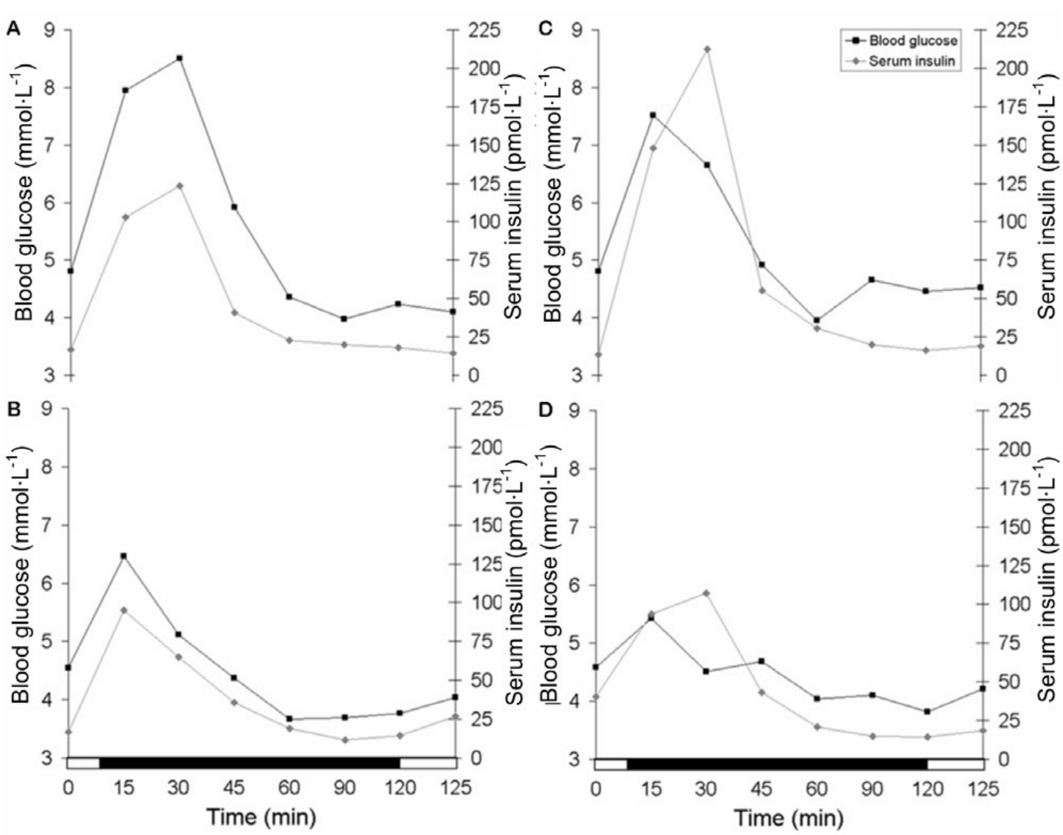


Fig. 3. *Mean Serum Insulin and Blood Glucose concentrations for nine endurance trained cyclists; (A) after ingestion of a high GI beverage at rest, (B) after ingestion of a high GI beverage followed by exercise, (C) after ingestion to a low GI beverage at rest, and (D) after ingestion of a low GI beverage followed by exercise*

peaking together at 15 min in the exercise trials, and 30 min in the rest trials. However, ingestion of the LGI beverage resulted in insulin peaks at 30 min despite blood glucose peaking at 15 min after consumption. (Fig. 3).

Discussion

This is the first study in young male endurance athletes to investigate blood glucose and insulin responses to commercially available HGI and LGI beverages ingested either immediately prior to a 110-min bout of cycling, or at rest. The main finding of the present study is that the difference in glycemic response to HGI and LGI beverages is less pronounced when the glycemic response is measured during exercise, compared to at rest. This result seems to be attributable to exercise decreasing the blood glucose response with the HGI beverage to a greater extent than with the LGI beverage. The decreased blood glucose response during exercise was not unexpected as this has been reported previously (17, 18). The interactive effect of GI and exercise on blood glucose response was less expected and cannot be explained by the insulin response to the HGI and LGI trials.

The greater drop in blood glucose concentrations seen in response to the HGI beverage during exercise suggest a higher rate of glucose clearance in response to the HGI beverage than the LGI beverage. Several studies investigating the effects of pre-exercise feedings of low and high GI CHO (fed > 45 min prior to exercise) have demonstrated that feeding low GI CHO prior to exercise results in higher fat oxidation during exercise (19-21). In the current study the larger decrease in blood glucose concentration during exercise after consuming the HGI beverage may be attributable to a higher glucose utilisation in these trials. However, without substrate utilisation measurements, which were not possible in the current study due to limited access to equipment, and time constraints, this suggestion remains speculative. Additionally, because the beverages were not matched for energy and other macronutrients the possible confounding of the higher energy and protein content of the LGI beverage cannot be eliminated. The addition of protein to CHO often produces a higher insulin response then when CHO is fed alone, especially when supplements are not balanced for energy. However, the difference in insulin response between the two beverages in the current study was not statistically significant.

Significant differences in insulin response may not have been detected in the current study for two reasons: 1) the higher than expected insulin response to the LGI beverage; and 2) the high variability in insulin response during the first 30 min following ingestion. The high insulin response may have been due to the milk protein and cocoa components of the LGI beverage, both of which have been reported to produce disparity between glucose and insulin responses (22-24). The high variability in insulin response between participants is common (25), and may indicate differences in insulin sensitivity between participants. Clearly there is a need for further research to be conducted, feeding high and low GI CHO immediately prior to exercise, controlling for energy and protein content, as well as CHO.

Carbohydrate feeding prior to exercise is reported to cause increases in blood glucose concentration, increased insulin secretion, and resultant hypoglycemia in some individuals (26, 27). In the current study blood glucose concentration below 3.0 $mmol \cdot L^{-1}$ was not recorded in any of the trials, despite the fact that the amount of CHO provided was at the threshold identified as a risk factor for hypoglycemia (50 g) (27). This result indicates that even a 10 min warm-up at 50% $\dot{V}O_2max$ may be enough to prevent hypoglycemia.

In the current study, blood glucose concentration returned to baseline between 45 and 60 min after consumption of both the HGI and LGI beverages, in both the at-rest and exercise trials. Maintenance of blood glucose during endurance exercise is desirable for optimising performance, however, neither of these beverages seem to hold an advantage over the other in this regard. Participants did not consume any additional CHO during 110 min of cycling. However, current recommendations for optimal performance suggest additional CHO should be consumed during events lasting longer than 90 min. The results of the current study highlight the importance of consuming additional CHO throughout the exercise session to maintain blood glucose levels. They also indicate that the amount, rather than the GI of the CHO, is more important when CHO is consumed during exercise. However, without measures of substrate utilisation, immune response and performance, benefits associated with the consumption of LGI CHO that have been reported elsewhere (19, 28, 29) cannot be disregarded.

In conclusion, the results of the present study indicate blood glucose response to both high and low GI beverages is lower when they are consumed immediately prior to exercise, compared to at rest. This effect is more pronounced after the ingestion of a HGI beverage, compared to a LGI beverage. The results also indicate that the consumption of neither HGI or LGI beverages cause hypoglycemia during 110 min of cycling when consumed after a 10 min warm-up, and that neither beverage was superior in maintaining blood glucose concentrations during exercise. Based on these results athletes should let individual preference, rather than GI, guide their choice of pre-exercise CHO beverages, and may benefit from a warm-up prior to consumption if they are at risk of symptoms of hypoglycemia.

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