Effects of GI Meals on Intermittent Exercise

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- pre-exercise nutrition
- carbohydrates
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Abstract

Pre-exercise meals or single foods containing low glycaemic index (LGI) carbohydrates (CHO) have been shown to enhance performance prior to prolonged steady state exercise compared to high glycaemic index (HGI) CHO. This study investigated the impact of HGI and LGI pre-exercise meals on intermittent high intensity exercise. Nine male recreational football players performed a football specific protocol followed by a 1 km time trial 3.5 h after ingesting 1 of 2 isoenergetic test meals (HGI: 870.3 kcal, LGI: 889.5 kcal), which were either HGI (GI: 80) or LGI (GI: 44). Blood glucose, fatty acids (FA),

glycerol, β -hydroxybutyrate, lactate and insulin were assessed before, during, and after the exercise bout, whilst rates of CHO and fat oxidation were determined at 4 time points during the protocol. No significant differences were found for the 1 km time trial (LGI: 210.2 ± 19.1 s; HGI: 215.8 ± 22.6 s) (mean $\pm$ SD), nor for any of the other variables measured ($P > 0.05$) apart from a significant condition effect with FA and significant interaction effects observed for glucose, β -hydroxybutyrate and lactate ($P < 0.05$). These findings suggest that the type of CHO ingested in a pre-match meal has no significant impact on performance or metabolic responses during 90 min of intermittent high intensity exercise.

Introduction

A primary cause of fatigue in football and similar intermittent sports is the depletion of muscle glycogen. Previous research [26] has observed both a significant reduction in muscle glycogen after a football match, and also that distance covered in the second half was reduced for players with a lower starting level of muscle glycogen compared to those with a higher level. The need for high carbohydrate (CHO) diets prior to prolonged intermittent exercise was reinforced [1] by demonstrating a greater exercise capacity following a 48 h high CHO diet (65% energy intake from CHO) compared to a control diet (39% energy intake from CHO). There is also evidence that carbohydrate feeding prior to an activity has a significant impact on subsequent performance [23,24] either by enhancing muscle glycogen stores or ensuring availability of blood glucose in the later stages of exercise. Taken together, these studies highlight the importance of ingesting sufficient CHO to maintain adequate levels of muscle glycogen prior to an intermittent field sport activity such as football.

Carbohydrate foods may be categorised by their ability to increase blood glucose; a concept which has resulted in the term glycaemic index (GI). The GI was initially developed to enable health-care professionals to prescribe diets of low glycaemic index (LGI) or high glycaemic index (HGI) foods to assist blood glucose control in diabetics [16]. In a sport and exercise context, the GI has been used to investigate the influence of pre-exercise carbohydrate intake on subsequent performance and metabolism. The application of GI for sport was first studied in 1991 [32] and concluded that a LGI food (i.e. lentils) produced a greater endurance capacity compared to a HGI food (i.e. potatoes) fed 1 h before cycling to exhaustion at 65–70% $\text{VO}_{2\text{max}}$. Subsequently, it has been found that a LGI meal improved 16 km time trial performance following a 5 km run at 70% $\text{VO}_{2\text{max}}$ [35], whilst others [8] have observed a significant increase in time to fatigue at 100% $\text{VO}_{2\text{max}}$ after cycling 2 h at 70% $\text{VO}_{2\text{max}}$ when fed a LGI meal. Recently, a study investigating the effects of GI on football performance, measured by total distance covered during 5 sprints throughout the last 15 min of a football protocol,

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Table 1 Energy, macronutrient content and GI of the test meals.

Food	Amount	Carbohydrate (g)	Protein (g)	Fat (g)	Energy (kcal)	GI
High GI meal						
lucozade original	380ml	65.4	0	0	245.3	95
water	210ml	–	–	–	–	–
askash rice	63 g	50	4.5	0.1	206.4	78
chicken breast	100 g	0.3	26.1	5.8	157.7	0
tomato based sauce	300 g	23.1	5.1	17.1	260.9	49
total	–	138.8	35.7	23	870.3	80
Low GI meal						
apple juice	590ml	65.5	0.6	0	248.0	40
basmati rice	63 g	44.8	6.1	0.8	199.6	48
chicken breast	100g	0.3	26.1	5.8	157.7	0
tomato based sauce	300g	23.1	5.1	17.1	260.9	49
total	–	133.7	37.9	23.7	866.3	44

found no performance benefits between meals of varying GI [19]. However, the meals used in this study did not reflect that of current practise within sport, as only one item of food was administered (low GI: boiled red lentils. High GI: instant mash potato with egg whites and ketchup). Other studies have found no effects on performance with LGI pre-exercise meals, although they have observed a metabolic shift to an increase in fat oxidation and a lower insulinaemic response [10, 11, 27]. The equivocal results are possibly due to variations in exercise duration and intensity, test meal composition, and the timing of ingestion. Furthermore, many of the studies comparing high and low GI meals [8, 10, 20, 27, 28] fail to offer complete meals typical of pre-training or pre-competition. In addition the timing of the meals often does not replicate that employed in elite sport, where athletes would typically eat meals 3–4 h prior to competition. This investigation compared a HGI and a LGI meal fed to participants 3.5 h prior to 90 min of intermittent high intensity exercise. This approach conveys a realistic scenario commonly observed in the professional game as rounded meals rather than individual food components are consumed within this pre-match time frame. We hypothesised that the LGI meal would promote fat availability and oxidation, maintain greater glucose stability in the postprandial period, and result in enhanced 1 km running performance after 90 min of intermittent high intensity exercise.

Method

Participants

Nine male recreational football players, all of whom trained twice a week and played a weekly competitive match were recruited for the study (Age: 21 ± 3 years, body mass [BM]: 74.4 ± 4.4 kg, body height 180 ± 8 cm). Participants provided written informed consent and the study was approved by the University Ethics Committee. Furthermore, the study was performed in accordance with the ethical standards of the International Journal of Sports Medicine [15].

Experimental design

Each participant was required to attend the laboratory on a minimum of 4 separate occasions. The first 2 were for familiarisation of the intermittent treadmill protocol and the 1 km performance test. Familiarisation of the 1 km performance test was achieved when test-retest times were within 2%. The final 2 visits were to

complete the experimental conditions, which were conducted in a counterbalanced, randomized manner separated by 7 days.

Test meals

Test meals were matched for macronutrient content and fluid. The size of test meals represented approximately 2 g/kg BM for a 70 kg participant. This amount was used as meals of greater quantity were deemed too large to consume. Participant's diet in the 24 h period prior to the first condition was recorded in a food diary, the subsequent trial was undertaken following the participant's verbal confirmation that the previous diet was followed. On the morning of both conditions, participants consumed the same standardised breakfast, of cereal, toast and fruit juice (total energy=377 kcal; CHO=79 g; Fat=3 g; Protein=13 g), which was consumed at 08:00. Participants abstained from alcohol and any physical exercise for 48 h prior to the test. • **Table 1** provides macronutrient details of the meals with their GI value and energy content. GI values were derived from previous reports [12] and the GI of the meal was calculated using the mixed-meal method [34].

Protocol

Following collection of the first venous blood sample (20 mL) at approximately 11:10, participants consumed the test meal at 11:30 (i.e. 3.5 h before the start of exercise which replicates the current practice of professional footballers). Blood glucose samples (Glucose Hemocue 201+, Hemocue, Ångelholm, Sweden) were also collected from finger prick samples pre-meal, and at 5, 30, and 60 min post meal. During the postprandial period, participants drank 1 L of water and rested until they returned to the laboratory at 14:30 for the pre-exercise blood sample. Participants completed a standardised warm up consisting of light jogging and static stretching prior to the start of the protocol at 15:00. The football specific protocol was an amended football protocol [9] completed on a motorised treadmill (H/P Cosmos Pulsar, Nussdorf-Traunstein, Germany). This protocol has been used in a previous study investigating hydration strategies for football [7]. The protocol imitates the activity patterns that occur in football matches and include bouts of walking (31–39 s), jogging (41–46 s), cruising (41–45 s), sprinting (16–21 s) and standing. The proportion of each individual activity is similar to those obtained from motion analysis [25]. The protocol comprises of two 22 min 30 s blocks to comprise one half of 45 min; a total of 4 blocks with a 15 min half time constituted the whole trial.

Fig. 1 Time trial performance.

Blood samples were collected after 10, 20 and 30 min into the first half of the protocol and immediately analysed for blood glucose to check for evidence of hypoglycaemia. A 15 min half time break was provided during which subjects drank 5 mL.kg⁻¹ of water and a further venous blood sample was collected. The second 45 min was a replication of activity patterns experienced during the first 45 min, totalling 90 min. A final venous blood sample was collected immediately post-exercise before participants ran the 1 km performance test.

The performance test was a self-paced 1 km time trial during which participants controlled the treadmill speed but were blinded to the actual speeds and time displayed on the treadmill. A performance test rather than a test for exercise capacity (i.e., time to fatigue) was deemed more appropriate and represented a consideration of 'what was left in the fuel tank'. Furthermore, such a high intensity task would necessitate use of all muscle fibres, although the type IIx fibres would be significantly employed [14].

At 4 time points during the protocol (10, 35, 55, and 80 min) expired gas was measured (Cortex Metamax online gas analyser, Cortex, Leipzig, Germany) from which calculations of fat and CHO oxidation were made [13]. The expired gas collections were collected in a similar fashion to previous authors [1], during which the measures were collected for 5 min during a range of exercise intensities but ending with a low intensity bout. In addition, the first sample was not collected until after 10 min, which should ensure CO₂ metabolism was in a steady state.

Subjective measurements of rating of perceived exertion [5] were recorded every 5 min, while hunger and gut fullness scales [31] were recorded every 15 min. Heart rate was continually measured and averaged over 5 min (Polar S610, Polar, Kempele, Finland).

Venous blood samples were collected from the antecubital vein pre-meal, pre-exercise, at half time, and post exercise, and analysed for fatty acid (FA), glycerol, β -hydroxybutyrate and lactic acid (RX Daytona clinical chemistry analyser, Randox, Co. Antrim, UK). Serum samples were collected following the same method as described above, for the analysis of insulin (Immulite 1000 immunoassay analyser, Siemens Healthcare Diagnostics, Illinois, USA). Blood glucose samples (Glucose Hemocue 201+, Hemocue, Ängelholm, Sweden) were collected at the same time points, but analysed separately to ensure a continual analysis from capillary blood. Intra assay coefficient of variation was

2.27% for glucose, 3.71% for FA, 0.60% for glycerol, 5.33% for β -hydroxybutyrate, 2.15% for lactic acid and 3.54% for insulin.

Statistics

SPSS software (version 17 SPSS, Chicago, IL) was used for data entry and analysis. Analysis of variance for repeated measures on 2 factors (experimental condition and time) was used to analyse differences in the physiologic and metabolic responses in both trials. If a significant interaction was obtained, a least significance difference post hoc test was used to determine the location of the variance [4]. A paired t-test was used to analyse time trial performance times. Differences were considered significant at $P < 0.05$. All data is presented as the mean $\pm$ SD.

Results

Performance

One of the participants was unable to complete one of the timed runs due to a musculoskeletal injury and so the data are based on $n = 8$. No significant difference was found between conditions for the 1 km time trial ($P > 0.05$). Completion times were 210.2 ± 19.1 s for LGI and 215.8 ± 22.6 s for the HGI which represented a 5.6 s (or 2.78%) faster completion after LGI. Furthermore, 5 out of 8 participants were faster after LGI, 2 were faster following HGI, and 1 produced identical results (● Fig. 1).

Blood glucose prior to exercise

No significant differences were observed between conditions, but significant differences were seen for time ($P = 0.008$) and for an interaction ($P = 0.050$). For both conditions the blood glucose concentration increased following consumption of the test meals with the HGI meal producing a greater increase from 4.6 mmol.L^{-1} to 7.2 mmol.L^{-1} compared to 4.9 mmol.L^{-1} to 5.7 mmol.L^{-1} after LGI. Blood glucose values subsequently decreased throughout the postprandial period with HGI resulting in a mean value of 4.0 mmol.L^{-1} prior to the start of exercise, whereas the blood glucose response for LGI remained more constant following the initial increase, resulting in a mean value of 4.8 mmol.L^{-1} prior to the start of exercise (● Fig. 2).

Blood glucose during exercise

No significant differences were observed between conditions, time or an interaction during exercise ($P > 0.05$). Blood glucose remained similar throughout exercise for both conditions (● Fig. 2).

Serum insulin

Serum insulin concentration increased for both conditions following the test meals, with no significant differences evident between conditions, time or interactions ($P > 0.05$) (● Fig. 2).

Plasma metabolites

No significant difference between conditions or interactions was seen for glycerol ($P > 0.05$), although a significant effect of time was observed ($P = 0.001$) as glycerol concentrations increased throughout exercise. Significant differences were observed between conditions for FA ($P = 0.022$) along with a significant time effect ($P = 0.001$), but no interaction effect was observed ($P > 0.05$). FA concentrations remained similar following consumption of the tests meals, but LGI resulted in a greater increase

Fig. 2 **a** Blood glucose concentration prior to the test meal and throughout the postprandial period and subsequent protocol. **b** Insulin concentration prior to the test meal and throughout exercise.

* significant interactions occur

in FA rising from 0.10 mmol.L^{-1} at the onset of exercise to 1.70 mmol.L^{-1} post exercise, compared to $0.07\text{--}1.33 \text{ mmol.L}^{-1}$ for HGI. Significant time ($P=0.001$) and interaction ($P=0.001$) effects were observed for β -hydroxybutyrate with a post exercise result of $0.106 \text{ mmol.L}^{-1}$ for LGI compared to $0.058 \text{ mmol.L}^{-1}$ for the HGI. Lactate concentrations increased from rest throughout exercise, with only a slight decrease from half time to post exercise in HGI. No significant differences were found between conditions, but a significant difference over time was observed ($P=0.002$), as was a significant interaction ($P=0.020$) (● Fig. 3).

Rate of fat and CHO oxidation

Rates of CHO and fat oxidation were similar throughout both conditions. No significant condition or interaction effects were observed, but a time effect was seen for both CHO ($P=0.012$) and fat ($P=0.013$) (● Fig. 4).

Heart Rate and subjective rating scales HR and RPE both increased significantly over time ($P=0.001$), but there was no significant difference between conditions. Subjective ratings of fullness and hunger showed no significant difference between conditions, over time or an interaction ($P>0.05$) (● Fig. 5).

Discussion

The main finding from this study was that consuming a LGI or HGI meal concordant with a time mirroring current practice in professional (and most recreational) football, and prior to intermittent high intensity exercise, had no significant effect on performance or metabolic responses with our recreational football players. These findings are in support of investigations that have observed no significant changes in fat oxidation [35], fat metabolites [22,29], or performance [10,11,19,20,27,33] following a LGI food/meal. In contrast some studies have observed enhanced fat oxidation [30,33], increased FA or glycerol or ketone body concentrations [10,11,27,30], and even performance [8,22,32,35] with LGI foods. The difference accruing from these investigations is that they either invariably use single foods [10,11,27] or modes of exercise such as prolonged steady state cycling

[10,11,22,27] or prolonged steady state running [36]. However, a recent study explored the effect of GI meals on prolonged intermittent exercise, but the so-called meals were single foods which do not reflect the general practise in most sports [20], even though the results of performance agree with our findings. Present data cannot support the proposal that a LGI pre-exercise meal prior to football activity (in the time window utilised) improves performance due to an increase in fat oxidation and metabolism, and thereby possibly spare muscle glycogen.

The rationale for the use of LGI meals in sport and exercise is predicated on the purported shift in substrate utilisation and oxidation that occurs with a LGI meal providing a greater level of fat oxidation [36] and thus sparing muscle glycogen stores. Fat and CHO oxidation rates between LGI and HGI did not differ in the current study, which could reflect the intermittent high intensity protocol used to replicate the activity patterns seen in football. Where modifications in substrate oxidation are observed in other studies, they have commonly employed a continuous mode of exercise.

Significant depletion of the body's muscle glycogen stores have been shown to occur during a football match [3,26] due to the high intensity and duration of the sport. Researchers [3,26] have reported the utilization of muscle glycogen by measuring pre and post levels and conclusively highlighted the need for high CHO meals. However, a recent investigation [20] also measured muscle glycogen levels between high GI and low GI foods in addition to a fasted control. They found a significantly greater muscle glycogen level following the CHO meals compared to the fasted control, but failed to measure any pre-meal or pre-exercise levels and therefore cannot report utilization between the high and low GI meals and the fasted control.

The insulinaemic and glucose response seen with the complete meals consumed in the current study is not entirely representative of the typical response expected with singular LGI and HGI foods. The response with the LGI meal is as expected with small elevations in serum insulin and blood glucose, with a return to baseline 30 min post meal that remains constant throughout the 3 h postprandial period. However, the HGI meal resulted in a greater, but non significant, rise in serum insulin with a concomitant significant elevation in post meal blood glucose increase,

Fig. 3 a Glycerol, b NEFA, c β-hydroxybutyrate and d Lactate concentration prior to the test meal and throughout exercise.

* indicate where significant interactions occur.

indicate a significant condition effect

Fig. 4 a CHO oxidation and b Fat oxidation measure during exercise.

Fig. 5 a Heart rate, b RPE, c Fullness and d Hunger throughout exercise.

which then decreased throughout the postprandial period and the following exercise protocol with a slight rebound hypoglycaemia evident just before the onset of exercise. An increase in serum insulin may have been observed in the current study if further serum insulin analysis had occurred in the immediate postprandial period [30]. Similar glycaemic responses have been reported previously when comparing LGI and HGI foods prior to exercise [11,30,36]. The potential effects of rebound hypoglycaemia [10,11,27,36] could prove detrimental to performance and metabolism in the early stages of competition and warrants further investigation.

Lower glucose and insulin responses that are attributed to the LGI meals have been suggested to promote satiety and suppress hunger [21]. However, the current study found no difference between meals for gut fullness or ratings of hunger. Furthermore, the glucose and insulin responses did not differ significantly during exercise. This may be due to the intermittent nature of the exercise or the inclusion of practical meals that contain protein as well as the CHO, as protein catabolism can be insulinogenic. Throughout the exercise there was no evidence of hypoglycaemia at any stage, or even any evidence of hyperglycaemia at the end of the exercise between conditions. These findings concur with previous investigations [17] who even argue that the risk of reduced performance is minimal with pre-exercise CHO feeding despite relative large metabolic changes.

An increase in FA was observed towards the latter stages of the exercise bout, which was similar to previous reports [2,18]. This may be mediated by the frequent rest and low intensity exercise periods interspersed throughout the intermittent activity that allows for greater blood flow to the adipose tissue. Also the likely

increase in epinephrine (with a concomitant decrease in insulin) supports the likelihood of an increase in lipolysis. Furthermore, the increase in FA is significantly augmented after a LGI meal compared to a HGI meal, probably as a consequence of the hyperglycaemic and hyperinsulinemic responses to the HGI meal in the postprandial period. Such findings have previously been observed [11] and suggest a persistent effect of hyperinsulinemia, even after insulin and glucose levels return to normal. The current study also found a significant interaction effect with β -hydroxybutyrate which indicates a greater ketosis at the end of the exercise.

The current study found a 2.78% faster completion of the 1 km run after LGI, and although not significant, 5 out of 8 participants were faster after LGI. This is similar to other studies that found no significant performance differences between conditions with tests measuring work done in a given period of time or set distance [6,10,11,19,20,27]. Only one study has found significant results in favour of a LGI meal prior to exercise with a 21 km time trial [35]. Most studies that have found differences between conditions [8,32] have employed a time-to-exhaustion protocol which would not be seen in a sporting competition.

In conclusion, the pre-exercise meal has no significant impact on performance after a 90 min intermittent high intensity exercise, suggesting that the type of CHO ingested does not radically alter substrate metabolism. However, the fact that 5 out of 8 participants provided faster times for the 1 km run warrants further investigation as does examination of muscle glycogen concentration post activity in order to provide an insight into likely substrate utilisation.

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