

EFFECTS OF HIGH AND LOW CONCENTRATION CARBOHYDRATE SOLUTIONS ON ENDURANCE PERFORMANCE CONSUMED PRIOR TO AND DURING INTENSE, INTERMITTENT EXERCISE

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Abstract

The aim of the study was to compare the effects of high and low concentration carbohydrate (CHO) solutions on the endurance performance of recreational, male soccer players consumed prior to and during intense, intermittent exercise.

Methods: Seven participants consumed four different fluids using a randomised double blind procedure, an 8% carbohydrate electrolyte solution (2.5% galactose and 5.5% glucose polymer) (8% CES), a 2.5% carbohydrate (2.5% galactose) electrolyte solution (2.5% CES), an electrolyte solution (E) and water (W). A further three participants acted as controls by consuming E only on four occasions. We used the Loughborough Intermittent Shuttle Test (LIST) to simulate the intense, intermittent nature of a soccer match. The LIST protocol consists of two parts: Part A required walking, jogging and sprinting, utilising a 20 m shuttle procedure, for 75 min, recovering for 3 min every 15 min. Part B required participants to perform intermittent running to exhaustion, alternating between 55% and 95% of their predicted maximal oxygen uptake. Each beverage was administered immediately prior to exercise ($5 \text{ ml} \cdot \text{kg}^{-1}$) and every 15 min thereafter ($2 \text{ ml} \cdot \text{kg}^{-1}$) until the conclusion of Part A.

Results: The performance run times for Part B (mean $\pm$ SD) were 16.3 ± 1.5 min (8% CES), 11.1 ± 1.2 min (2.5% CES), 10.0 ± 1.0 min (E) and 9.3 ± 0.9 min (W). The 8% CES beverage produced a significantly greater time to exhaustion (Part B) than the other drinks (5.0 ± 1.5 min, $P < 0.05$).

Conclusions: A high CHO concentration formulation (8% CES) is associated with a significant increase in endurance performance during intense, intermittent exercise in recreational, male soccer players.

Key words: sports drink, carbohydrate, electrolyte, galactose, endurance performance, team sports

Introduction

Endurance performance can be improved in activities lasting greater than 40 minutes by ingesting water or a carbohydrate (CHO) solution, and the effects of both are independent and additive [1-4]. The type, quantity and formulation of the fluid appear to be highly relevant to endurance performance [5]. A recent Position Stand from the American College of Sports Medicine [6] has indicated that fluid intake during endurance activities should be sufficient to limit body mass loss to less than 2% of the pre-exercise mass. The assertion that the consumption of plain water alone is effective in prolonging performance during endurance activity is less well supported than the evidence for a beneficial effect of a diluted CHO-electrolyte solution [7]. However, it is difficult to quantify how much CHO is oxidized during prolonged exercise and thus plays a metabolic role [1,8]. Maughan and colleagues [1] argued that an alternative explanation could be that the addition of smaller concentrations of CHO could promote more rapid water absorption in the small intestine and thus provide more efficient rehydration. During endurance-based activities, ingested fluid

will be effective only if it is emptied swiftly from the stomach and absorbed rapidly in the small intestine. For this reason, concentrated CHO solutions may be less effective as they result in a temporary loss of body water into the small intestine [8].

The potential drawbacks of inadequate fluid replacement and provision of energy during prolonged exercise have been well documented [e.g. 7,9] but research is limited especially during exercise of a high intensity, intermittent nature [10-13]. Fluids containing both CHO and electrolytes are thought to be preferable in overcoming fatigue arising from concurrent depletion of glycogen reserves and dehydration though there is little investigation into the most appropriate CHO concentrations for this type of activity. The provision of CHO up to an hour before exercise can lead to hypoglycaemia though blood glucose concentrations may be augmented by the provision of CHO taken during intermittent activity [11,12]. The likelihood of changes in muscle glycogen under these conditions is unclear but there is some evidence that absolute blood glucose concentrations may be directly related to glycogenolysis, in that glycogen is spared

when blood glucose concentration is maintained but increasingly used if not [14,15]. Thus, we wanted to compare the effects of a high versus low CHO solution on the endurance performance of recreational, male soccer players prior to and during intense, intermittent exercise.

Methods

Ethical approval was provided by the Leeds Hospital Trust ethical committee, and all participants were required to give written informed consent. Peak oxygen uptake ($\dot{V}O_{2peak}$) was estimated through a progressive 20 m multi-stage fitness test, and from this a prediction of 55% and 95% $\dot{V}O_{2peak}$ could be calculated [16]. Volunteers familiarised themselves with running at 55% and 95% of their predicted $\dot{V}O_{2peak}$ for a 15 min period. This formed part of the Loughborough Intermittent Shuttle Test (LIST) running protocol [10].

Drink formulations

Individuals completed four separate exercise trials conducted over a three-week period. The tests were randomised and administered in a double blind fashion. On each occasion they consumed either an 8.0% w/v CHO-electrolyte solution which contained 2.5% galactose and 5.5% glucose polymer [glucidex 6] solution (8% CES), a 2.5% w/v CHO-electrolyte solution (2.5% galactose) (2.5% CES), an electrolyte solution (E) or water (W). With the exception of water, the sodium concentration of the drinks was $35 \text{ mmol} \cdot \text{l}^{-1}$. A further three participants acted as controls (CON) and were asked to perform the test on four separate occasions consuming the E solution. This group was incorporated into the study to assess any training/order effects of the testing. The participants were required to consume the solutions immediately prior to the start of exercise ($5 \text{ ml} \cdot \text{kg}^{-1}$ body mass (BM)), and every 15 min thereafter ($2 \text{ ml} \cdot \text{kg}^{-1}$ BM) until the end of Part A of the LIST [10]. Prior to the study a pilot investigation was conducted to ensure that fluids were appropriately matched for colour, texture and taste with the exception of water. Solutions were administered in a double-blind design. It was important to include both an electrolyte and water group because there is evidence that fluid balances may be disturbed in those participants consuming water during exercise in which sweat losses may be high [17]. The electrolyte solution for CON contained sodium ions in the same concentration as the CHO solutions.

Exercise Testing Protocol

Two days prior to testing, volunteers were requested not to participate in any strenuous physical activity and were expected to consume their normal diet. All participants voided prior to measurement of

nude body mass and this was recorded both pre- and post- exercise. A progressive standardised warm-up involving gentle jogging and stretching over a 10 min period was completed. Immediately prior to exercise all participants consumed their prescribed beverages.

Exercise testing was conducted on an indoor, wooden gymnasium floor. Ambient temperature was maintained between 19 and 21°C, and humidity was between 40 and 45% throughout the study. An electronic bleep directed through a CD player was used to pace running intensity levels. The test area was identified by a series of cone markers. The LIST protocol has been fully described elsewhere and the interested reader is directed to Nicholas and co-workers [10] for full details of the exercise protocol. Briefly, the protocol consisted of two parts. Part A required walking, jogging and sprinting, utilising a 20m shuttle procedure, for 75 min. Each 15 min interval was followed by a 3 min rest period. Part B required the participant to run to exhaustion, alternately running each 20 m shuttle at an intensity equivalent to 55 and 95% predicted $\dot{V}O_{2peak}$. These values were based on performance in the 20 m multi-stage shuttle test. Fatigue was defined as the inability to maintain the required running speed for two consecutive distances of 20 m at the higher running speed.

Sprint times were also recorded during each phase of Part A. Measurement was in one direction using two-pairs of infra-red photo electric cells (Cranlea, Birmingham, UK) placed 15 m apart. During each 3 min interval of Part A, subjective ratings of perceived exertion and gut fullness (determined by a linear scale) were obtained. At the end of Part A, participants voided prior to the commencement of Part B. Following Part B, during the 45 min post-exercise period, the consumption of water was allowed *ad libitum*. The amount consumed was recorded and accounted for when re-weighing each participant while monitoring changes in body mass. During both Part A and B of the exercise protocol, capillary blood samples were taken using the Autoclix blood sampler (Roche Diagnostics Ltd, Lewes, UK). Samples were collected in heparinised glass capillaries and temporarily stored at $< 4^{\circ}\text{C}$ until the end of the test. Immediately following testing, analysis for lactate and glucose content was performed using the Analox blood analyser (Analox PGM-7, Hammersmith, UK).

Statistical Analysis

Group data for each variable at rest and peak exercise are presented as mean $\pm$ standard deviation (SD). Physiological and blood biochemical responses in all trials were analysed using a two-way analysis of variance (ANOVA) for repeated measures (treatment $\times$ time). Significant differences between means were identified using a Scheffé *post-hoc* test. Statistical

analyses were performed using SPSS software (version 11), and statistical significance assumed at $P < 0.05$.

Results

Ten (experimental group = 7; control group = 3) recreational, male soccer players (mean $\pm$ SD) (age 23 ± 2 years; stature 1.80 ± 0.06 m; body mass 86 ± 5 kg; predicted $\dot{V}O_{2\text{peak}}$ of 52 ± 4 ml $\cdot$ kg $^{-1}$ $\cdot$ min $^{-1}$) volunteered for the study. Seven participants completed the experimental section of the study, whilst three participants acted as aged-matched controls. The mean performance run times in Part B of the LIST for the four solutions were 16.3 ± 1.5 min (8% CES), 11.1 ± 1.2 min (2.5% CES), 10.0 ± 1.0 min (E), 9.3 ± 0.9 min (W), and 9.8 ± 0.3 min (CON) respectively (Table 1). Thus, when participants ingested 8% CES they ran on average, for 5.0 ± 1.5 min longer than when drinking the next best drink ($P < 0.001$). Distance covered by all

participants in Part A was 10.8 ± 0.2 km. Mean distance covered in Part B was 3.3 ± 0.3 km (8% CES), 2.2 ± 0.3 km (2.5% CES), 2.0 ± 0.2 km (E), 1.9 ± 0.2 km (W), 2.0 ± 0.2 km (CON). The CON group did not demonstrate any training/order effects during the randomisation process (Figure 1).

Blood glucose concentrations were maintained within a normal biological range (3.4 to 7.3 mmol $\cdot$ l $^{-1}$) at each stage of the trial (Figure 2). Following the ingestion of the 8% CES formulation, mean blood glucose concentrations were significantly higher after 15 min ($P < 0.05$) and 30 min ($P < 0.05$) of exercise than after consumption of any of the other fluids.

Following the LIST protocol, the highest loss in mean BM occurred during the W trial (-1.9 kg $\cdot$ -2.2% BM) though this was not significantly different to other solutions (Table 2; $P > 0.05$). Mean blood lactate concentration increased significantly from resting

Table 1. Mean run time to exhaustion (min) for each of the four drinks

Participant	2.5% CES	8% CES	E	W
1	10.6	15.0	8.8	9.2
2	12.0	17.3	11.5	10.8
3	10.0	15.9	10.1	8.3
4	12.5	18.7	11.1	9.2
5	12.3	17.0	10.5	10.2
6	10.9	16.0	9.4	8.8
7	9.5	14.4	8.9	8.9
Mean	11.1	16.3	10.0	9.3
SD ($\pm$)	1.2	1.5	1.0	0.9

2.5% CES: 2.5% CHO-electrolyte solution; 8% CES: 8% CHO-electrolyte solution; E: electrolyte only solution; W: water

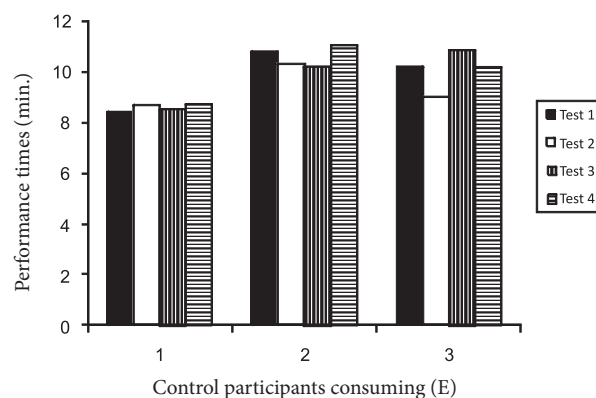
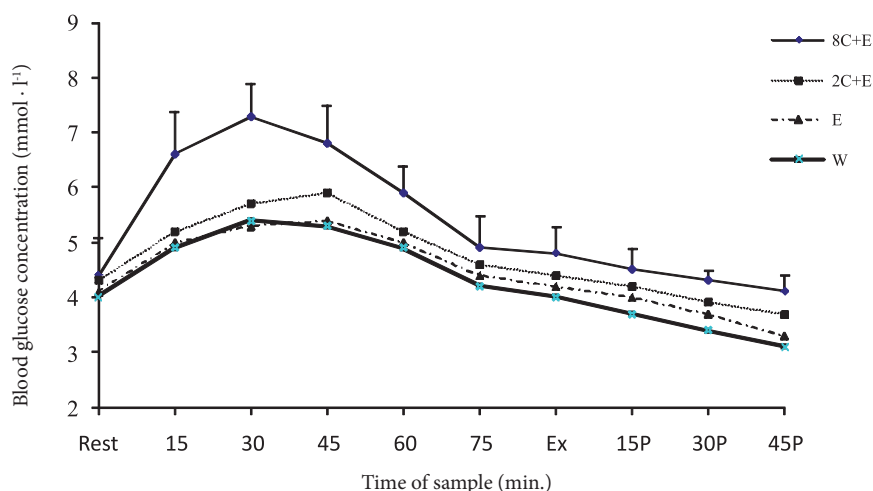


Figure 1. Mean run time performance in the control group



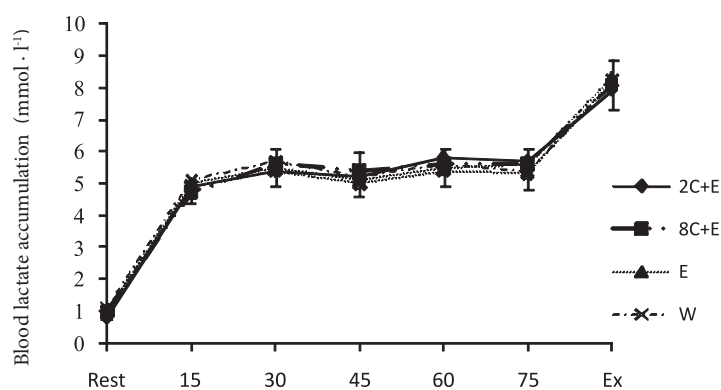
Ex = at exhaustion; 15P= 15min post exercise; 30P= 30min post exercise; 45P= 45min post exercise
*significant difference between 8% CES and next highest glucose concentration ($P < 0.05$). 2.5% CES: 2.5% CHO-electrolyte solution; 8% CES: 8% CHO-electrolyte solution; E: electrolyte only solution; W: water

Figure 2. Relationship between blood glucose concentration (mmol $\cdot$ l $^{-1}$) and timing of sample

Table 2. Mean changes in body mass (BM) and urine production according to type of fluid consumed (mean $\pm$ SD)

	8% CES	2.5% CES	E	W	CON
Mean BM differences (kg)	1.7 $\pm$ 0.5	1.5 $\pm$ 0.6	1.8 $\pm$ 0.7	1.9 $\pm$ 0.8	1.7 $\pm$ 0.7
Mean BM loss(%)	1.9	1.8	2.1	2.2	2.0
Volume of urine produced (ml)	111 $\pm$ 6	97 $\pm$ 4	107 $\pm$ 5	115 $\pm$ 6	101 $\pm$ 5

2.5% CES: 2.5% CHO-electrolyte solution; 8% CES: 8% CHO-electrolyte solution; E: electrolyte only solution; W: water



Ex = At exhaustion; 2.5% CES: 2.5% CHO-electrolyte solution; 8% CES: 8% CHO-electrolyte solution; E: electrolyte only solution; W: water

Figure 3. Changes in blood lactate accumulation during the LIST protocol according to type of fluid consumed

levels to exhaustion following LIST ($P < 0.05$, Figure 3), but there were no significant differences in lactate concentration between fluid trials ($P > 0.05$).

Ratings of perceived exertion (RPE) were not significantly different between fluid trials, reaching a mean value of RPE of 11.3 ± 1.2 after 15 min of exercise, and whilst increasing, remained similar throughout all time points including exhaustion (19.7 ± 0.4 ; $P > 0.05$). Urine production varied slightly between trials. Mean values varied from between 97 to 115 ml after 75 min of exercise, depending on the beverage consumed (Table 2). The W trial produced the most urine but conversely, participants who consumed 2.5% CES produced the least urine. There were no differences in heart rate responses between trials ($P > 0.05$). Heart rate data ranged from 86 ± 7 beats $\cdot$ min $^{-1}$ at rest to 191 ± 2 beats $\cdot$ min $^{-1}$ at exhaustion. There were no differences in sprint velocities between trials at 15 min (5.73 ± 0.40) through to 75 min of exercise (5.87 ± 0.45 ; $P > 0.05$). On a gut fullness scale, using a Likert scale from 0 (empty) to 8 (full), participants reported no differences between trials in gut fullness at 15 min (2.3 ± 0.3) through to 75 min of exercise (2.8 ± 0.4 ; $P > 0.05$).

Discussion

The aim of our study was to compare the effects of a high versus low concentration carbohydrate (CHO) solution on the endurance performance of recreational, male soccer players consumed prior to and during intense, intermittent exercise. Our findings

show the benefits of providing an energy dense (8% CHO) rehydration solution immediately before and during high intensity, intermittent exercise. The run time to exhaustion was increased by 46% when taking the high-energy drink (8% CES). Previous work has reported that CHO concentration should not exceed 8%, as higher concentrations could compromise gastric emptying [18,19].

Our results are comparable to previous data [20] that demonstrated a significant increase of blood glucose concentration at the start of exercise followed by a linear decrease. However, Hasson & Barnes [20] adopted an insulogenic drink and participants consumed the beverage over the course of a 30 min continuous cycle ergometer protocol (80% predicted maximal oxygen uptake). In our study, the use of an energy dense drink (8% CES) was associated with an initial increase in blood glucose concentration almost certainly as a result of an increased absorption from the gut in response to the oral intake. This was not a feature of any of the other drinks used including the pure galactose drink (2.5% CES). It is highly likely that the increased use of this exogenous energy source during the initial stages of such exercise was associated with sparing of muscle glycogen such that in the latter stages, time to exhaustion was extended. This is consistent with similar effects seen in the studies of high intensity intermittent running [10] and in continuous exercise [8]. Thus, intermittent and discontinuous exercise such as shuttle running does not act to alter radically

or moderate the normal response to exogenous energy as seen in similar but continuous exercise situations when capacity to exhaustion is extended [21].

The consumption of an 8% CES formulation during the exercise period was not associated with evidence of subsequent hypoglycaemia; blood glucose concentrations during the latter exercise, although marginally greater, were not significantly different to those achieved by the use of the 2.5% CES mixture, electrolyte or plain water. These data are consistent with a reduction in insulin secretion such that homeostasis of blood glucose concentration was achieved during periods of increased disposal of exogenous carbohydrate. The inclusion of galactose, a non-insulogenic sugar [22], may facilitate this effect if hepatic conversion of galactose to glucose matches disposal of glucose to working muscle. Clearly this could spare oxidation of muscle glycogen. It is not clear whether the extended endurance performance found following ingestion of the 8% CES solution is a feature of using in part a non-insulogenic sugar (galactose), or the result of a reduced secretion of insulin due to the actual glucose load in this type of protocol. The consumption of fluid immediately before exercise is less likely to induce insulin secretion. It is, however, well known that inopportune hypoglycaemia during exercise limits subsequent performance due to premature depletion of glycogen [23] and since this was not a feature of this protocol and our findings, it is likely that either or both types of changes in control could be true. Exogenous CHO could under such conditions result in sparing the oxidation of endogenous CHO stores.

Dehydration during endurance activities impairs both physical and mental performance, therefore, fluid replacement strategies are essential when significant sweat loss occurs [24]. Our study indicates that there is an endurance benefit for a higher CHO concentration to be taken during intermittent exercise of a type typical in team games. These data indicate that the advantage occurs in a subsequent performance test and as such the limitations of duration and intensity of exercise are clearly key factors in the benefits gained. Thus, the use of such fluids should be evaluated against the actual requirements of a game with particular reference to the latter stages, otherwise other fluids may be just as useful. Higher CHO concentration formulations showed no disadvantage over electrolyte and water but the availability of exogenous CHO is important in producing significant increases in the time to exhaustion in Part B of the LIST protocol. It would appear that the LIST is an appropriate test for evaluating the differences between various sports drinks in a situation that has some validity for field games such as soccer and rugby.

In conclusion, a high CHO concentration formulation (8% CES) is associated with a significant increase in endurance performance during intense, intermittent exercise in recreational, male soccer players.

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