Fluid Provision and Metabolic Responses to Soccer-Specific Exercise

N. D. CLARKE, B. DRUST, D. P. M. MACLAREN and T. REILLY

Research Institute for Sport and Exercise Sciences, Liverpool John Moores University,

Henry Cotton Campus, 15-21 Webster Street, Liverpool, L3 2ET, UK

Tel: 0151 231 4273

Fax: 0151 231 4353

e-mail: n.d.clarke@ljmu.ac.uk

Abstract

The present study aimed to investigate the impact on metabolism of altering the timing and volume of ingested carbohydrate during soccer-specific exercise. Twelve soccer players performed a soccer-specific protocol on 3 occasions. On two, 7 $ml \cdot kg^{-1}$ carbohydrate-electrolyte or placebo were ingested at 0 and 45 min. On a third, the same total volume of carbohydrate-electrolyte was consumed but at 0, 15, 30, 45, 60 and 75 min. Carbohydrate-electrolyte ingestion increased blood glucose, insulin and carbohydrate oxidation, whilst suppressing NEFA, glycerol and fat oxidation ($P<0.05$) although manipulating the schedule of carbohydrate ingestion elicited similar metabolic responses ($P>0.05$). However, consuming fluid in small volumes reduced the sensation of gut fullness ($P<0.05$). The results demonstrated that when the total volume of carbohydrate consumed is equal, manipulating the timing and volume of ingestion elicits similar metabolic responses. Furthermore, consuming a small volume of fluid at regular intervals reduces the sensation of gut fullness.

Key words: Fluid, Carbohydrate, Metabolism, Gut fullness.

Introduction

A significant reduction in the glycogen content of the thigh muscles of players has been observed at the completion of a soccer match (Jacobs et al. 1982). This decline in glycogen stores is reflected in lower running speeds and shorter distances covered during the second half (Saltin 1973). There are data supporting the consumption of carbohydrate during exercise simulating the work-rate of competitive soccer (Kirkendall 1993), but this evidence is somewhat inconclusive and may depend upon the measurement tool, such as run to exhaustion or high-intensity sprints. Nicholas et al. (1995) established that by ingesting a 6.9% carbohydrate solution, exercise capacity in a simulation of exercise equivalent to the intensity of playing soccer could be improved, whereas sprint performance was not. Zeederberg et al. (1996) investigated the effect of ingesting a 6.9% glucose-polymer solution before a match and at half-time and failed to show measurable benefits of glucose-polymer ingestion on motor skills of soccer players when games were played in a cool environment. Their study involved measurement of discrete skills, whereas Nicholas et al. (1995) assessed time to exhaustion after 75 min of intermittent exercise. Leatt and Jacobs (1989) also investigated the effect of ingesting a glucose-polymer solution before a game and at half-time. Whilst performance aspects were not measured, a higher muscle glycogen concentration was found post-game compared with the control group, leading the authors to conclude that carbohydrate ingestion does not hinder performance and may delay the onset of fatigue.

Dehydration has also been linked with fatigue during soccer play and the intensity of exercise associated with a competitive match is high enough to induce appreciable thermal stress, causing players to lose up to 3 litres of sweat (Ekblom 1986). There are not sufficient opportunities, i.e. breaks in play, during a match for players to ingest enough fluid to replace what is lost through sweating. Another problem with fluid ingestion is that gastric discomfort may result from attempting to ingest a large volume of fluid at half-time (Reilly and Ekblom 2005). As a consequence there are opportunities for

enhancing performance during a game by adopting optimal refuelling and rehydration regimes.

Gastric emptying is considered a limiting factor in fluid replacement (Shi and Gisolfi 1998). Studies using a single large ingestion (Costill and Saltin 1974) or repeated smaller ingestions (Duchman et al. 1997) have demonstrated that gastric emptying is strongly affected by gastric volume. Gastric emptying is also influenced by exercise intensity, and Leiper et al. (2005; 2001) demonstrated that the intensity corresponding to a soccer match is sufficient to slow gastric emptying. The drinking strategy employed in the majority of studies related to soccer has been to ingest a large volume before activity and again at half-time, despite frequent administration of carbohydrate being shown to be necessary to improve performance during prolonged exercise (Fielding et al. 1985). Nevertheless, the effect of frequent fluid ingestion during soccer-specific exercise has not been previously investigated.

The exercise protocol was designed to simulate the work-rate in competitive soccer match-play. The aim of the experiment was to investigate the effect of consuming a carbohydrate-electrolyte drink either in a single bolus or more frequent ingestion on metabolic responses to soccer-specific exercise.

Methods

Subjects

Twelve male university soccer players of age: 24±1 years; height: 1.80±0.1 m; body mass: 76.5±3 kg; $\dot{V}O_{2max}$: 61.1±1 $ml \cdot kg^{-1} \cdot min^{-1}$ participated in this study. All subjects provided written informed consent to participate, in accordance with Liverpool John Moores University's ethical procedures.

Experimental Protocol

Each subject attended the laboratory on six separate occasions. During the first visit the subject's $\dot{V}O_{2max}$ was assessed whilst exercising on a motorised treadmill (H/P/Cosmos Pulsar 4.0, H/P/Cosmos Sports & Medical GmbH, Nussdorf-Traunstein, Germany) using a graded exercise test to volitional exhaustion. During this session height and body mass were recorded.

The subjects also undertook two familiarisation sessions consisting of two blocks of a soccer-specific protocol (i.e. 30 minutes). Subjects performed the soccer-specific protocol (Figure 1) on a motorised treadmill (H/P/Cosmos Pulsar 4.0, H/P/Cosmos Sports & Medical GmbH, Nussdorf-Traunstein, Germany) and was a modified version of that designed by Drust et al. (2000). The protocol consisted of the various exercise intensities that are regularly observed during competitive soccer matches (i.e. walking, jogging, cruising and sprinting). The proportions of these activities were based on the observations of Reilly and Thomas (1976), although utility movements (e.g. backwards and sideward movements) were not included. These activities were divided between walking and jogging, the proportion of time for each activity and corresponding speed being as follows: static pauses 3.8% (0 $km \cdot h^{-1}$); walking 27.9% (4 $km \cdot h^{-1}$); jogging 38.9% (12 $km \cdot h^{-1}$); cruising 19.9% (15 $km \cdot h^{-1}$); sprinting 9.5% (19 $km \cdot h^{-1}$). The duration of each activity was determined by matching the proportions observed by Reilly and Thomas (1976) to the total time of the block, after deduction of the total time for the changes in treadmill speed had been made. The duration of each discrete bout was as follows: static 8.0 s; walking 27.8 s; jogging 38.7 s; cruising 34.8 s; sprinting 9.4 s.

Subjects completed the full soccer-specific protocol (90 min activity divided into 2 x 45 min identical period, separated by a period of 15 min, representing half-time. Each 45-min period consisted of three 15-min blocks; Figure 2) on three occasions in "normal" laboratory conditions (mean temperature 18.4±0.3ºC, relative humidity 58.6±2%, wind speed 0 $m \cdot s^{-1}$). During one session, 7 $ml \cdot kg^{-1}$ body mass of carbohydrate electrolyte

solution (Lucozade Sport, GlaxoSmithKline, Gloucestershire, UK) was consumed before (mean 538±19 ml) and at half-time (mean 538±19 ml, i.e. mean total 1075±38 ml). The emphasis was on volume and hence the treatment was designated CHOv. On another occasion a placebo (a similarly coloured, flavoured and textured electrolyte solution) (GlaxoSmithKline, Gloucestershire, UK) was consumed at the same time points (PLA). During the other session the same total volume of carbohydrate electrolyte was consumed but drinking occurred more frequently and in smaller volumes (i.e. 179±6 ml) at 0, 15, 30, 45, 60 and 75 min of exercise, during the walking phase of the block (CHOf). During the carbohydrate trials the total amount of carbohydrate ingested was 68±1.4 g at a rate of 45±0.9 $g \cdot h^{-1}$.

For the three days prior to the first test session, subjects completed a diet and physical activity diary, which was adhered to for subsequent sessions. Approximately 3-4 hours prior to testing, subjects swallowed a heat-sensitive telemetry pill (HQ inc., Palmetto, Florida, USA), which was used to measure core temperature. Thirty minutes before the subject was due to commence exercising, a venous blood sample was taken. A standard 15-min warm up was performed, consisting of jogging, sprinting and stretching, before the subject began the 90 min of exercise

Physiological Measurements

During the soccer-specific protocol core temperature and heart rate were measured continuously using a heat-sensitive telemetry system and short-range radio telemetry (Polar, Sports Tester, Polar Electro, Kempele, Finland), respectively. Core body temperature was monitored continuously by means of an ingestible temperature sensor pill and external data logger (HQ inc., Florida, USA). Data were presented as the mean value for each 15-min block.

During a 2-min (10-12 min) period of each 15-min block, oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) were recorded using an on-line automated gas

analyser (Metalyzer3B, Cortex Biophysic GmbH, Leipzig, Germany). Total carbohydrate and fat oxidation rates (g/min) were subsequently calculated by using stoichiometric equations of Frayn (1983) with the assumption that protein oxidation during exercise was negligible:

$$\text{Carbohydrate oxidation } (g \cdot min^{-1}) = 4.55\,\dot{V}CO_2 - 3.21\,\dot{V}O_2 \quad (1)$$

$$\text{Fat oxidation } (g \cdot min^{-1}) = 1.67(\dot{V}O_2 - \dot{V}CO_2) \quad (2)$$

where $\dot{V}O_2$ and $\dot{V}CO_2$ represent oxygen consumption and carbon dioxide production, respectively, in litres per minute.

Rating of perceived exertion (RPE) was measured using Borg's (1970) 6-20 scale. Gut fullness and thirst were measured using 100-mm visual analogue scales (VAS) during the final walking period of each 15-min block. Gut fullness and thirst were also measured before and after fluid consumption pre-exercise and at half-time.

Blood sampling and analysis

Venous blood samples (16 ml) were taken from an antecubital vein in the forearm by a trained phlebotomist using the Vacutainer™ collection system (Becton Dickinson Vacutainer Systems Europe, Meylan, France). A blood sample was taken 30 min before exercise commenced, at half-time and at the completion. Blood samples were collected in serum separation tubes for insulin, plastic tubes containing EDTA for adrenaline, NEFA and glycerol, and lithium heparin tubes for glucose. All tubes were centrifuged and the plasma was frozen at -80°C for analysis. Plasma samples were analysed for glucose (Glucose oxidase, Instrumentation Laboratory, Monza, Italy), glycerol (Randox Laboratories ltd, Co. Antrim, UK), Non-esterified fatty acid (NEFA) (NEFA-C, Wacko Chemicals GmbH, Neuss, Germany), adrenaline (Catcombi ELISA, IBL GmbH, Hamberg, Germany), insulin (Insulin ELISA, DRG Instruments GmbH, Germany).

Statistical analysis

All variables were analysed using two-way ANOVAs with repeated measures except for sweat loss, which was analysed using a one-way ANOVA with repeated measures. All results are reported as the mean ± the standard error of the mean (SEM) and a level of $P<0.05$ was considered statistically significant.

Results

Pre-exercise plasma glucose concentration was similar for all three trials (Figure 3a). There was a significant effect of trial of the concentration on plasma glucose ($F_{2,22}=12.33$; $P<0.05$). The plasma glucose concentration was significantly higher at 45 and 90 min during CHOf than during PLA. There was also a significant effect of time ($F_{2,22}=6.18$; $P<0.05$). During trials CHOv and CHOf, plasma glucose concentration was elevated significantly above resting levels at half-time and at completion of the soccer-specific protocol ($P<0.05$). The repeated measures ANOVA identified a significant time and trial interaction ($F_{4,44}=3.11$; $P<0.05$); plasma glucose remained relatively constant during the first half of the placebo trial, in contrast to during the carbohydrate trials when plasma glucose increased markedly. Plasma glucose decreased in all trials during the second half although no subjects were found to be hypoglycaemic.

The repeated measures ANOVA revealed that there was a significant trial effect on the plasma concentration of NEFA ($F_{2,22}=2.69$; $P<0.05$; Figure 3b). The concentration of NEFA was significantly higher at the completion of the soccer-specific protocol when placebo was ingested compared with CHOv. There was a significant effect of time on the concentration of plasma NEFA ($F_{2,22}=34.68$; $P<0.05$), which increased significantly between each time point as exercise progressed. There was also a significant ($F_{4,44}=3.58$; $P<0.05$) trial and time interaction; after half-time NEFA concentration increased markedly more during PLA compared with CHOv and CHOf, in which it increased at a steady rate.

The plasma concentration of glycerol was significantly affected by the trial ($F_{2,22}$=4.83; P>0.05), and the concentration was significantly (P<0.05) higher during the PLA trial compared with CHOv (Figure 3c). Plasma glycerol concentration increased significantly between each time point ($F_{2,22}$=49.14; P<0.05). There was also a significant ($F_{4,44}$=3.07; P<0.05) trial and time interaction; after half-time glycerol concentration increased markedly more during PLA compared with CHOv and CHOf.

The concentration of adrenaline was found to be similar during all trials ($F_{2,22}$=0.95; P>0.05, Figure 4a), and increased significantly ($F_{2,22}$=23.82; P<0.05;) between each time point during all trials. The repeated measures ANOVA also revealed a significant interaction ($F_{2,26}$=5.81; P<0.05). Between half-time and the completion of the soccer-specific protocol adrenaline concentration increased at a greater rate during PLA (1.78±0.12 nmol·l^{-1}) compared with CHOv (1.59±0.11 nmol·l^{-1}) and CHOf (1.61±0.11 nmol·l^{-1}).

There was a significant trial effect on the concentration of serum insulin ($F_{2,17}$=5.42; P<0.05; Figure 4b). The serum insulin concentration was significantly higher during CHOf than during the placebo trial. The repeated measures ANOVA identified a significant time and trial interaction ($F_{3,35}$=3.19; P<0.05) whereby, serum insulin concentration increased during the first half of CHOf, whereas it decreased during CHOv and more markedly during PLA. All trials demonstrated a decreased insulin response during the second half.

The repeated measures ANOVA showed carbohydrate oxidation was significantly ($F_{2,22}$=4.56; P<0.05) affected by the experimental treatments (Figure 5a). Carbohydrate oxidation was greater during CHOf compared to PLA (P<0.05). Carbohydrate oxidation was significantly ($F_{23,29}$=2.42; P<0.05) lower during block 6 compared with blocks 1 and 5 during PLA although there were no significant differences between CHOf and CHOv (P>0.05), No significant interaction was observed ($F_{4,44}$=1.63; P>0.05). The rate of fat oxidation during PLA was significantly higher ($F_{2,22}$=11.30; P<0.05, Figure 5b) compared with the CHOf and CHOv trials but did not identify a significant effect of time ($F_{2,24}$=1.33; P>0.05) or interaction ($F_{4,40}$=1.33; P>0.05).

The sensation of gut fullness was significantly (F2,22=6.61; P<0.05) less during CHOf compared with PLA and CHOv (Figure 6a). There was also a significant effect of time, (F3,16=13.56; P<0.05); pairwise comparisons showed that gut fullness increased significantly after fluid ingestion and was significantly higher after fluid ingestion pre-exercise and at half-time compared with during blocks 3 and 6 of the protocol. There was a significant interaction (F5,51=3.81; P<0.05). Gut fullness was relatively constant throughout CHOf; in comparison during PLA and CHOv it increased markedly after fluid ingestion and decreased throughout each half of the soccer-specific protocol.

There was no significant difference in thirst between the trials ($F_{2,22}$=2.91; *P*>0.05, Figure 6b). There was a significant difference between time points, ($F_{3,29}$=15.36; *P*<0.05), and pairwise comparisons showed these differences occurred between post-fluid ingestion and the end of the first half. The subjective feeling of thirst was significantly higher (*P*<0.05) throughout the second half, compared with during the half-time interval. A significant interaction between time and condition was also identified ($F_{16,176}$=2.78; *P*<0.05). The feeling of thirst was relatively consistent throughout CHOf, in contrast during PLA and CHOv, the feeling of thirst decreased markedly after fluid ingestion before increasing steadily throughout the subsequent 45 min.

There was no significant trial effect on core temperature ($F_{2,22}$=1.99; *P*>0.05, Figure 7). A significant effect of time was observed ($F_{5,55}$=44.95; *P*<0.05); pairwise comparisons demonstrated these differences occurred between the first block and the following five blocks. Core temperature increased significantly (*P*<0.05) during each half of the soccer-specific protocol, but there was no significant difference (*P*>0.05) between the end of the first half and the start of the second, i.e. the half-time fall in core temperature did not reach statistical significance. No significant interaction was identified ($F_{5,51}$=0.72; *P*>0.05).

There was no significant trial effect on heart rate ($F_{2,22}$=0.26; *P*>0.05, Table 1). Heart rate increased significantly ($F_{2,23}$=41.13; *P*<0.05) throughout each half of the soccer-specific protocol. There was also a significant interaction ($F_{3,37}$=3.21; *P*<0.05); heart rate

increased by a significantly greater margin during the second half of the PLA trial than during CHOv and CHOf (P<0.05). There was no significant ($F_{2,22}$=1.47; P>0.05) difference in RPE between trials (Table 1). A significant effect of time was detected ($F_{2,19}$=57.12; P<0.05), with RPE increasing significantly throughout each half of the soccer-specific protocol although no interaction was observed ($F_{5,49}$=1.20; P>0.05). There was no significant difference ($F_{2,22}$=1.536; P>0.05) in sweat loss between the three trials. The mean losses were: PLA (1.43±0.10 kg), CHOv (1.42±0.08 kg) and CHOf (1.43±0.12 kg).

Discussion

The main finding of the present study was that altering the timing and ingested volume of a carbohydrate-electrolyte solution did not significantly affect metabolism. In addition, it was reaffirmed that consuming a carbohydrate-electrolyte solution compared with PLA significantly increased plasma glucose concentration and carbohydrate oxidation, whilst NEFA, glycerol and fat oxidation were reduced.

Two of the most likely causes of fatigue during a soccer match are dehydration and muscle glycogen depletion (Reilly 1997). In the present study the ingestion of a carbohydrate solution, irrespective of timing and volume, during soccer-specific exercise significantly elevated plasma glucose levels. The higher, although not significant, plasma glucose concentration observed during CHOf compared with CHOv may be as consequence of the length of time between ingestion and the blood sample being drawn (45 min (CHOf) *vs.* 15 min (CHOv). Studies have demonstrated that plasma glucose levels are significantly higher 15-30 min following the ingestion of carbohydrate prior to exercise (Nicholas et al. 1995; Nicholas et al. 1999) than after 45-60 min of high-intensity intermittent exercise (Nicholas et al. 1995; Nicholas et al. 1999; Ostojic and Mazic 2002). Although the overall lack of a significant difference between the two carbohydrate trials may have been as a consequence of the same total volume of carbohydrate being ingested. The elevated blood glucose levels associated with

carbohydrate ingestion also support previous findings (Coyle et al. 1983; Nicholas et al. 1995; Wright et al. 1991), that the ingestion a carbohydrate solution during exercise can maintain or increase the concentration of blood glucose during exercise. Consuming a carbohydrate solution during exercise has also been demonstrated to attenuate the exercise induced decrease in plasma insulin (Coyle et al. 1986; Coyle et al. 1983), as was observed in the present study.

Plasma NEFA and glycerol concentrations increased during the soccer-specific protocol, with the greater increase occurring during the second half of the PLA trial. This observation suggests that consuming carbohydrate solution during exercise suppressed the release of NEFA and glycerol during CHOv and CHOf, possibly as an effect of an elevated insulin concentration. Coyle et al. (1991) reported that the concentration of plasma NEFA is depressed following the ingestion of carbohydrate during cycling, which is a consequence of the elevated insulin levels, as was observed in the present study. The increase in NEFA supports the findings of Bangsbo (1994), that the concentration of NEFA in the plasma increases during a soccer match, and more so during the second half. The adrenaline concentration increased significantly during the soccer-specific protocol, but was not significantly different between the trials. However, there was a tendency for adrenaline levels to be lower at the completion of the carbohydrate trials, similar to the findings of Coyle *et al.* (1983). A number of authors (Felig et al. 1982; Fritzsche et al. 2000) have reported that when carbohydrate is ingested the adrenaline response is blunted. This observation may be related to the large increase in insulin concentration associated with carbohydrate ingestion (Fritzsche et al. 2000). However, when carbohydrate is ingested during exercise and it does not affect insulin concentration, i.e. when the carbohydrate dose is low (~ 13 g $CHO \cdot h^{-1}$), the adrenaline response does not seem to be affected (Burgess et al. 1991; Mitchell et al. 1989).

Similar patterns of carbohydrate oxidation and fat oxidation were observed when carbohydrate was consumed during exercise, irrespective of timing and volume and were significantly different from the control condition. This result is similar to the findings of Wright et al. (1991), where in the trials in which carbohydrate was consumed, either

during exercise or as a pre-exercise meal, both RER and carbohydrate oxidation were significantly elevated compared to the placebo trial. The higher RER and carbohydrate oxidation after carbohydrate feedings were attributed to either greater muscle glycogenolysis or glucose uptake and oxidation (Wright et al. 1991), reflected in the significantly higher rate of carbohydrate oxidation during CHOf and CHOv compared to PLA in the present study. Since it appears that carbohydrate feeding reduces muscle glycogen degradation during prolonged exercise, especially in type 1 muscle fibres (Tsintzas et al. 1995) and intermittent exercise (Nicholas et al. 1999; Nicholas et al. 1994), the higher carbohydrate oxidation was most likely caused by increased blood glucose uptake and oxidation.

Despite the different timings and volume of fluid consumed there were no significant differences between trials in the subjective feeling of thirst. This observation is in contrast to Ferguson et al. (2005), who reported that the thirst response was higher when a small volume of fluid was consumed at 15-min intervals during exercise compared with a single bolus pre-exercise, although thirst was similar towards the end of exercise, when similar volumes had been ingested for both conditions. However, the study of Ferguson et al. (2005) was performed in the heat, which is likely to increase the sensation of thirst due to increased sweat loss. In the present study, irrespective of volume, thirst decreased significantly following the consumption of fluid at rest, prior to the soccer-specific intermittent protocol and at half-time. Gut fullness was significantly lower and relatively constant during CHOf compared with PLA and CHOv. In contrast during PLA and CHOv gut fullness increased sharply after fluid ingestion and decreased throughout the half of the protocol. Consuming large volumes of fluid increases gut fullness (perceived or actual), which may cause discomfort and adversely influence performance. Therefore, a small volume of fluid consumed regularly may be a preferable option. This option may not be practical during a soccer match, as there are not any scheduled breaks in play where fluid can be ingested.

There were no statistical differences in either heart rate or RPE between trials during the soccer-specific intermittent protocol, supporting the findings of Nicholas et al. (1995).

Core temperature increased significantly during all of the trials, but there was no difference between trials. These findings indicate that the physiological stress imposed by the protocol was similar in all three conditions. In contrast, previous studies have reported lower heart rate (Ferguson et al. 2005; Melin et al. 1994) and core temperature (Melin et al. 1994) following a single bolus compared with intermittent fluid intake, although these studies entailed low-intensity exercise (50% $\dot{V}O_{2max}$) and were performed in the heat and the subjects were previously dehydrated (Melin et al. 1994). In addition, these results suggest that 7 $ml \cdot kg^{-1}$ ingested at the start of each half is an adequate volume of fluid to consume to prevent dehydration during soccer-specific exercise, when performed in thermo-neutral conditions. The similar sweat loss values for the trials suggest that it is the total volume of fluid that is important in preventing dehydration, more so than the timing and volume.

The general recommendation for fluid ingestion during exercise is that fluid should be consumed early, and at regular intervals in an attempt to replace the water lost through sweating, or to consume the maximal amount that can be tolerated (Convertino et al. 1996). This study indicates that if sufficient carbohydrate-electrolyte solution is ingested before and at half-time, metabolism is not significantly affected when compared to consuming the same total volume ingested at the recommended 15-min intervals, supporting the findings of our previous study (Clarke et al. 2005). The absence of scheduled breaks in soccer may prevent players taking regular feedings of carbohydrate other than at half-time. These findings indicate that consuming a carbohydrate-electrolyte solution before a match and at half-time is a practical strategy for fluid provision during soccer at moderate ambient temperatures.

In conclusion, ingesting carbohydrate-electrolyte solution significantly affected plasma metabolites and increased carbohydrate oxidation. Also, when the total volume of fluid consumed was equal, manipulating the timing and volume of carbohydrate ingestion elicited the same metabolic responses. Furthermore, consuming a small volume of fluid at regular intervals, compared with a single large volume before and at half-time of the soccer-specific protocol, resulted in a reduced sensation of gut fullness. As there are no

scheduled breaks in soccer matches the results suggest that ingesting carbohydrate in a sports drink before a game and again at half-time is a practical strategy for fluid provision.

Acknowledgements

This study was supported by GlaxoSmithKline.

References

Bangsbo J (1994) The physiology of soccer, with special reference to intense intermittent exercise. Acta Physiol Scand (suppl) 151: 1-155

Burgess WA, Davis JM, Bartoli WP, Woods JA (1991) Failure of low dose carbohydrate feeding to attenuate glucoregulatory hormone responses and improve endurance performance. Int J Sport Nutr 1: 338-352

Clarke ND, Drust B, MacLaren DPM, Reilly T (2005) Strategies for hydration and energy provision during soccer-specific exercise. Int J Sport Nutr Exerc Metab 15: 625-640

Convertino VA, Armstrong LE, Coyle EF, Mack GW, Sawka MN, Senay LC, Sherman WM (1996) American College of Sports Medicine position stand - Exercise and fluid replacement. Med Sci Sports and Exerc 28: R1-R7

Costill DL, Saltin B (1974) Factors limiting gastric emptying during rest and exercise. J Appl Physiol 37: 679-683

Coyle EF, Coggan AR, Hemmert MK, Ivy JL (1986) Muscle glycogen utilization during prolonged strenuous exercise when fed carbohydrate. J Appl Physiol 61: 165-172

Coyle EF, Hagberg JM, Hurley BF, Martin WH, Ehsani AA, Holloszy JO (1983) Carbohydrate feeding during prolonged strenuous exercise can delay fatigue. J Appl Physiol 55: 230-235

Coyle EF, Hamilton MT, Alonso JG, Montain SJ, Ivy JL (1991) Carbohydrate metabolism during intense exercise when hyperglycemic. J Appl Physiol 70: 834-840

Drust B, Reilly T, Cable NT (2000) Physiological responses to laboratory-based soccer-specific intermittent and continuous exercise. J Sports Sci 18: 885-892

Duchman SM, Ryan AJ, Schedl HP, Summers RW, Bleier TL, Gisolfi CV (1997) Upper limit for intestinal absorption of a dilute glucose solution in men at rest. Med Sci Sports and Exerc 29: 482-488

Ekblom B (1986) Applied physiology of soccer. Sports Med 3: 50-60

Felig P, Cherif A, Minagawa A, Wahren J (1982) Hypoglycemia during prolonged exercise in normal men. N Eng J Med 306: 895-900

Ferguson MA, Mccoy S, Mosher PE (2005) Exercise in a hot environment: comparison of two different fluid intake patterns. J Sports Med Phys Fitness 45: 501-506

Fielding RA, Costill DL, Fink WJ, King DS, Hargreaves M, Kovaleski JE (1985) Effect of carbohydrate feeding frequencies and dosage on muscle glycogen use during exercise. Med Sci Sports and Exerc 17: 472-476

Frayn KN (1983) Calculation of substrate oxidation rates in vivo from gaseous exchange. J Appl Physiol 55: 628-634.

Fritzsche RG, Switzer TW, Hodgkinson BJ, Lee SH, Martin JC, Coyle EF (2000) Water and carbohydrate ingestion during prolonged exercise increase maximal neuromuscular power. J Appl Physiol 88: 730-737

Jacobs I, Westlin N, Karlsson J, Rasmusson M, Houghton B (1982) Muscle glycogen and diet in elite soccer players. Eur J Appl Physiol 48: 297-302

Kirkendall DT (1993) Effects of nutrition on performance in soccer. Med Sci Sports and Exerc 25: 1370-1374

Leatt PB, Jacobs I (1989) Effect of glucose polymer ingestion on glycogen depletion during a soccer match. Can J Sport Sci 14: 112-116

Leiper JB, Nicholas CW, Ali A, Williams C, Maughan RJ (2005) The effect of intermittent high-intensity running on gastric emptying of fluids in man. Med Sci Sports and Exerc 37: 240-247

Leiper JB, Prentice AS, Wrightson C, Maughan RJ (2001) Gastric emptying of a carbohydrate-electrolyte drink during a soccer match. Med Sci Sports and Exerc 33: 1932-1938

Melin B, Cure M, Jimenez C, Koulmann N, Savourey G, Bittel J (1994) Effect of ingestion pattern on rehydration and exercise performance subsequent to passive dehydration. Eur J Appl Physiol 68: 281-284

Mitchell JB, Costill DL, Houmard JA, Fink WJ, Pascoe DD, Pearson DR (1989) Influence of carbohydrate dosage on exercise performance and glycogen metabolism. J Appl Physiol 67: 1843-1849

Nicholas CW, Tsintzas K, Boobis L, Williams C (1999) Carbohydrate-electrolyte ingestion during intermittent high-intensity running. Med Sci Sports and Exerc 31: 1280-1286

Nicholas CW, Williams C, Boobis LH, Little N (1994) Effect of ingesting a carbohydrate-electrolyte beverage on muscle glycogen utilisation during high intensity, intermittent shuttle running. Clin Sci 87 (suppl.): 26

Nicholas CW, Williams C, Lakomy HK, Phillips G, Nowitz A (1995) Influence of ingesting a carbohydrate-electrolyte solution on endurance capacity during intermittent, high-intensity shuttle running. J Sports Sci 13: 283-290

Ostojic SM and Mazic S (2002) Effects of a carbohydrate-electrolyte drink on specific soccer tests and performance. J Sports Sci Med 1: 45-53

Reilly T (1997) Energetics of high-intensity exercise (soccer) with particular reference to fatigue J Sports Sci 15: 257-263

Reilly T, Ekblom B (2005) The use of recovery methods post-exercise. J Sports Sci 23: 619-627

Reilly T, Thomas V (1976) A motion analysis of work-rate in different positional roles in professional football match play. J Hum Mov Stud 7: 87-97

Saltin B (1973) Metabolic fundamentals in exercise. Med Sci Sports and Exerc 5: 137-146

Shi XC, Gisolfi CV (1998) Fluid and carbohydrate replacement during intermittent exercise. Sports Med 25: 157-172

Tsintzas OK, Williams C, Boobis L, Greenhaff P (1995) Carbohydrate ingestion and glycogen utilization in different muscle fibre types in man. J Physiol 489: 243-250

Wright DA, Sherman WM, Dernbach AR (1991) Carbohydrate feedings before, during, or in combination improve cycling endurance performance. J Appl Physiol 71: 1082-1088

Zeederberg C, Leach L, Lambert EV, Noakes TD, Dennis SC, Hawley JA (1996) The effect of carbohydrate ingestion on the motor skill proficiency of soccer players. Int J Sport Nutr 6: 348-355

Table 1: Heart rate and RPE during the soccer-specific protocol.

	Block					
	1	**2**	**3**	**4**	**5**	**6**
Heart rate (beats.min^{-1})						
PLA	152±4	155±4	157±4	157±4	163±3	168±3
CHOv	152±4	157±3	161±3	159±3	162±3	166±3
CHOf	155±4	159±3	161±4	159±4	160±4	166±3
RPE						
PLA	12.0±0.2	13.1±0.3	13.8±0.4	13.1±0.3	13.9±0.3	15.0±0.3
CHOv	11.9±0.2	12.5±0.3	13.3±.03	13.2±0.3	13.8±0.5	14.6±0.6
CHOf	11.9±0.3	12.6±0.3	13.2±0.3	13.3±0.3	13.6±0.3	14.3±0.4

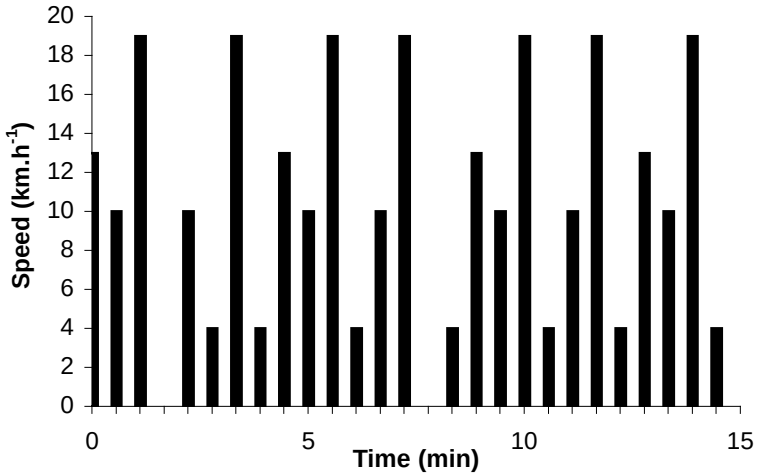

Figure 1: Activity profile of one 15 min block of the soccer-specific protocol.

0-15 min Block 1	16-30 min Block 2	31-45 min Block 3	15 min Half-time	46-60 min Block 4	61-75 min Block 5	76-90 min Block 6

Figure 2: Experimental protocol design

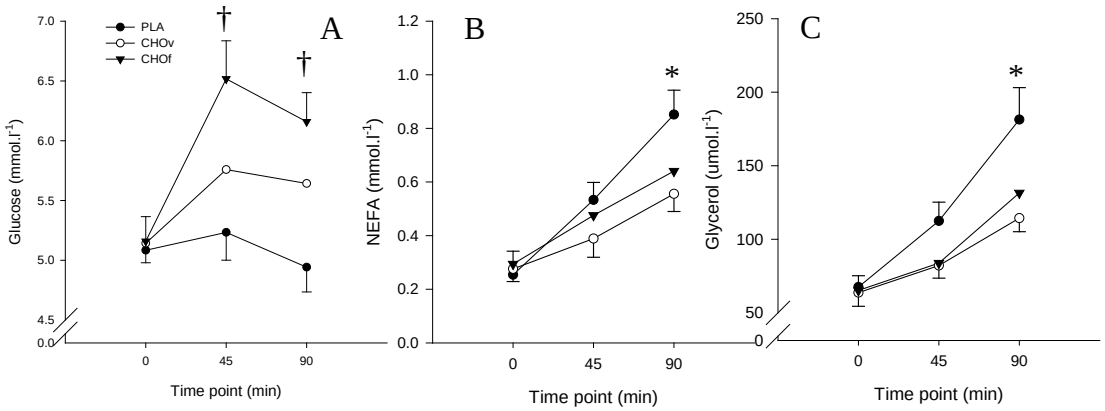

Figure 3: Plasma glucose (A), NEFA (B) and glycerol (C) concentrations during the soccer-specific protocol. † CHOf significantly greater than PLA. *PLA significantly greater than CHOv.

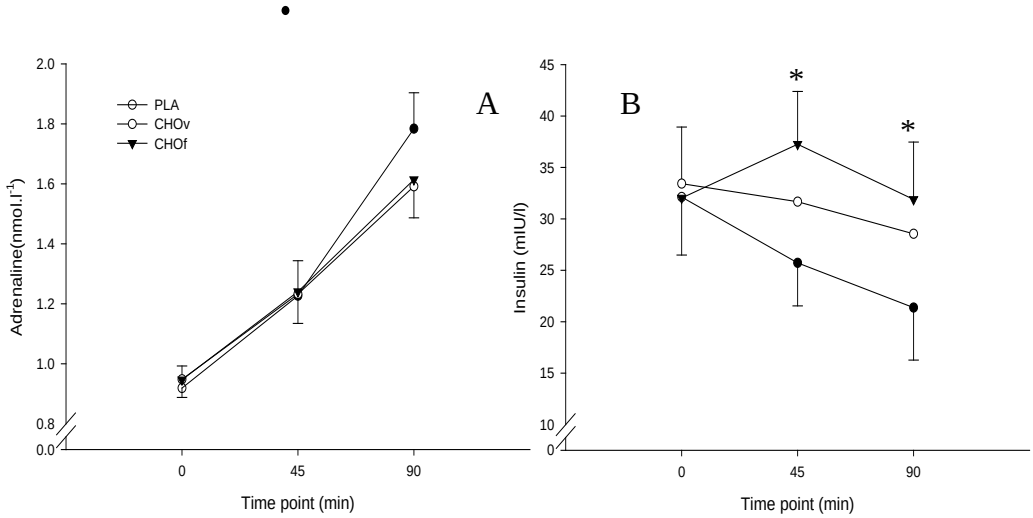

Figure 4: Plasma adrenaline (A) and Insulin (B) concentrations during the soccer-specific protocol. *CHOf significantly greater than PLA.

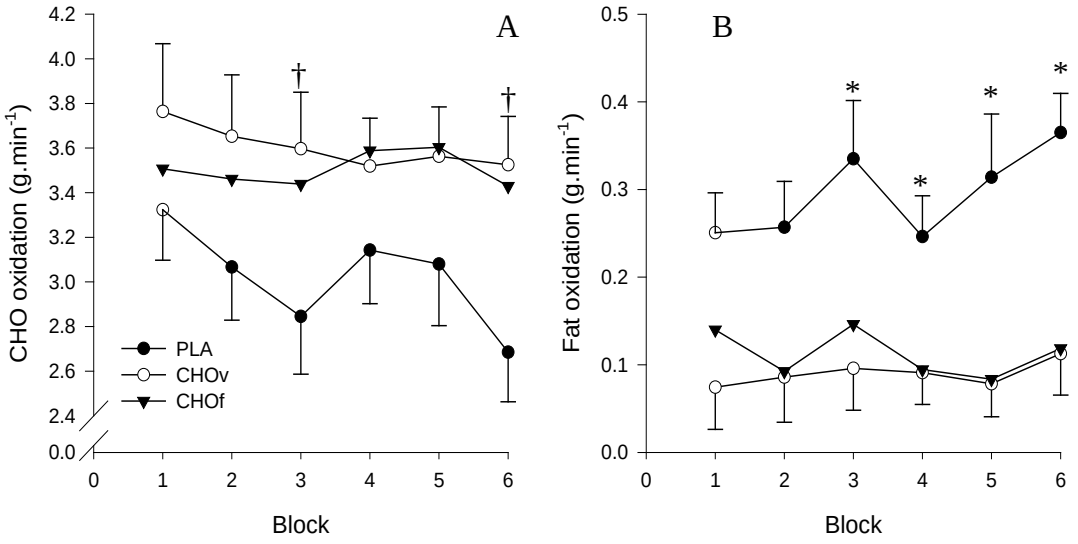

Figure 5: CHO (A) and fat (B) oxidation rates during the soccer-specific protocol. † CHOf and CHOv significantly greater than PLA. *PLA significantly greater than CHOv and CHOf.

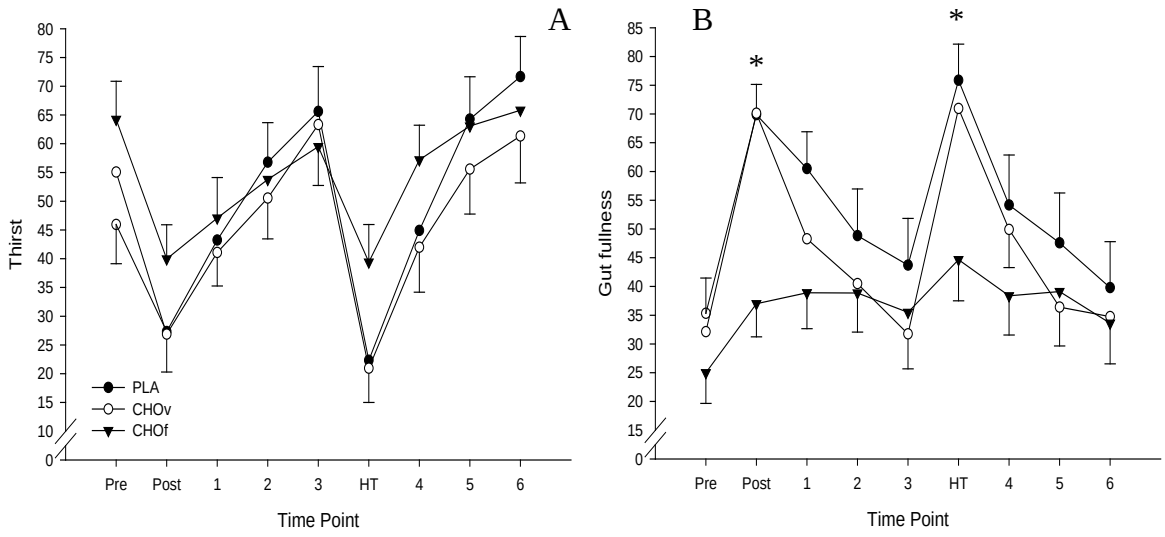

Figure 6: Subjective feelings of thirst (A) and gut fullness (B) during the soccer-specific protocol. Pre – pre-fluid, Post – post-fluid, HT – half-time, 1-6 soccer-specific protocol block. *PLAand CHOv significantly greater than CHOf**.**

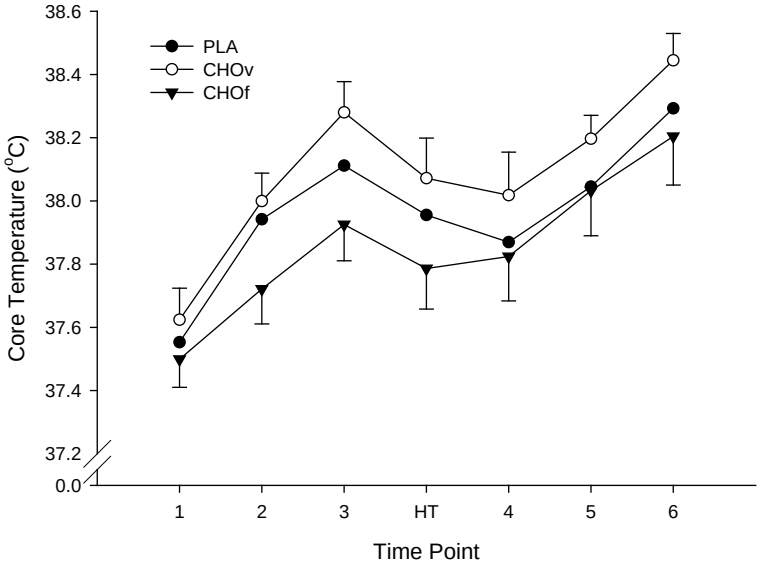

Figure 7: Core temperature during the soccer-specific protocol.