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The Ingestion of Combined Carbohydrates Does Not Alter Metabolic Responses or Performance Capacity During Soccer-Specific Exercise in the Heat Compared to Ingestion of a Single Carbohydrate

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Abstract

This study was designed to investigate the effect of ingesting a glucose plus fructose solution on the metabolic responses to soccer-specific exercise in the heat and the impact on subsequent exercise capacity. Eleven male soccer players performed a 90 min soccer-specific protocol on three occasions. Either 3 ml kg^{71} body mass of a solution containing glucose (1 g min^{71} glucose) (GLU), or glucose (0.66 g min^{71}) plus fructose (0.33 g min^{71}) (MIX) or placebo (PLA) was consumed every 15 minutes. Respiratory measures were undertaken at 15-min intervals, blood samples were drawn at rest, half-time and on completion of the protocol, and muscle glycogen concentration was assessed pre- and post-exercise. Following the soccer-specific protocol the Cunningham and Faulkner test was performed. No significant differences in postexercise muscle glycogen concentration (PLA, 62.99+8.39 mmol kg wet $weight^{71}$; GLU 68.62+2.70; mmol kg wet $weight^{71}$ and MIX 76.63+6.92 mmol kg wet $weight^{71}$) or exercise capacity (PLA, 73.62+8.61 s; GLU, 77.11+7.17 s; MIX, 83.04+9.65 s) were observed between treatments (P40.05). However, total carbohydrate oxidation was significantly increased during MIX compared with PLA (P50.05). These results suggest that when ingested in moderate amounts, the type of carbohydrate does not influence metabolism during soccer-specific intermittent exercise or affect performance capacity after exercise in the heat.

Keywords: soccer, fructose, glucose, muscle glycogen

Introduction

Soccer matches are regularly played in temperatures exceeding 308C. Precedents are the FIFA World Cup finals from 1994 to 2006 and the UEFA Euro 2004 tournament. Performing high-intensity intermittent exercise in the heat increases muscle glycogen utilisation, fluid loss and cardiovascular stress, and impairs performance (Morris, Nevill, Boobis, Macdonald, & Williams, 2005; Morris, Nevill, Lakomy, Nicholas, & Williams, 1998). The ingestion of fluid containing carbohydrate can offset dehydration, minimise disturbances in cardiovascular function, improve thermoregulation (Coyle & Coggan, 1984), reduce muscle glycogen utilisation (Nicholas, Tsintzas, Boobis, & Williams, 1999) and maintain blood glucose concentration (Coyle et al., 1983; Nicholas, Williams, Lakomy, Phillips, & Nowitz, 1995). These changes, either individually or in combination, can offset reductions in exercise tolerance and improve performance (Davis et al., 1988). Carbohydrate ingestion may, therefore, benefit intermittent exercise performance such as that which occurs in soccer (Reilly, 1997) in the heat.

There are data supporting the consumption of carbohydrate during exercise simulating the workrate of competitive soccer (Currell, Conway, & Jeukendrup, 2009; Kirkendall, 1993; Nicholas et al., 1995) in thermoneutral conditions and in the heat (Gant, Leiper, & Williams, 2007), although not consistently (Morris, Nevill, Thompson, Collie, & Williams, 2003). Despite reports of gastric emptying during intermittent exercise being similar for carbohydrate solutions and water (Gant et al., 2007), such a failure to improve performance may be related to the decrease in the oxidation rate of ingested carbohydrate (Jentjens, Wagenmakers, & Jeukendrup, 2002) and may be a direct consequence of a reduced absorptive capacity for carbohydrate in the intestine as a result of a decrease in intestinal blood flow (Brouns & Beckers, 1993). The absorptive capacity for carbohydrate is also limited by the saturation of the intestinal glucose transporter SGLT1 (Jeukendrup & Jentjens, 2000). Such saturation occurs when the rate of glucose ingestion exceeds 1 g min^{71} (Jeukendrup & Jentjens, 2000). However, the availability of fluid ingested during exercise in the heat is enhanced when glucose and fructose are combined compared with a glucose only solution (Davis, Burgess, Slentz, & Bartoli, 1990; Jentjens et al. 2006; Shi et al., 1995). This effect may occur due to separate transporters in the intestinal wall for glucose, and fructose thereby preventing the SGLT1 becoming saturated. Furthermore, when glucose and fructose are ingested simultaneously, hepatic lactate and glucose output increase along with the rate of total carbohydrate oxidation (Lecoultre et al., 2010). Consequently, ingesting a multi-carbohydrate drink may increase the intestinal absorption of fluid and hence the amount of carbohydrate available for oxidation which may enhance carbohydrate and fluid availability contributing to minimising factors that lead to fatigue in the heat (e.g. dehydration and increased muscle glycogen utilisation). The onset of fatigue may thereby be delayed and hence exercise performance may also be improved. This could also potentially explain the finding that in thermo-neutral conditions the consumption of fluid containing glucose and fructose has been shown to improve performance compared with the ingestion of a glucose-only solution (Currell & Jeukendrup, 2008; Triplett, Doyle, Rupp, & Benardot, 2010).

The majority of investigations into the effect of multi-carbohydrate solutions on carbohydrate oxidation have employed prolonged exercise protocols and high carbohydrate ingestion rates (1.5–2.4 g min^{71}) (Jentjens, Achten, & Jeukendrup, 2004a; Jentjens, Moseley, Waring, Harding, & Jeukendrup, 2004b; Jentjens et al., 2006; Jentjens, Venables, & Jeukendrup, 2004c) rather than intermittent exercise patterns typical of that observed during soccer matches. Increasing the availability of carbohydrate may be especially beneficial in soccer (Reilly, Drust, & Clarke, 2008) as the performance of high-intensity activities such as sprinting, kicking and tackling is important

for the outcome of the game. Furthermore, such high rates of carbohydrate ingestion are not recommended for prolonged exercise (Jeukendrup, 2008) where 0.5–1 g min^{71} is considered appropriate (Manore, Barr, & Butterfield, 2000). Therefore, the aim of the present study was to investigate the effect of ingesting moderate amounts of a glucose plus fructose drink compared with a glucose only solution on metabolism and exercise capacity during soccer-specific exercise performed in the heat.

Methods

Eleven male university soccer players of age: 27+2 years; height: 1.78+0.10 m; body mass: 76.1+ 2.3 kg; $V^{-}O_{2max}$: 63.1+1.6 ml kg^{71} min^{71} participated in this study. The study was approved by the local ethics committee and all participants provided written informed consent to participate.

Experimental design

During the first visit each participant's $V_{-} O_{2max}$ was assessed on a motorised treadmill (H/P/Cosmos Pulsar 4.0, H/P/Cosmos Sports & Medical GmbH, Germany) using a graded exercise test to volitional exhaustion. During this session height and body mass were also recorded. The participants undertook two familiarisation sessions, which consisted of two consecutive blocks (Figure 1) of the soccer-specific protocol i.e. 30 minutes on a motorised treadmill (H/ P/Cosmos Pulsar 4.0, H/P/Cosmos Sports & Medical GmbH, Germany) and the Cunningham and Faulkner (1969) treadmill test. Subsequently participants completed the full soccer-specific protocol on a motorised treadmill on three occasions in an environmental chamber (30.2 +0.58C and 45+4% relative humidity). During each performance of the soccer-specific protocol either a glucose-only (GLU), glucose plus fructose (MIX) or placebo (PLA) solution was ingested. During the soccer-specific protocol respiratory responses were measured at 15-min intervals, blood samples were drawn before exercise, at half-time and at the

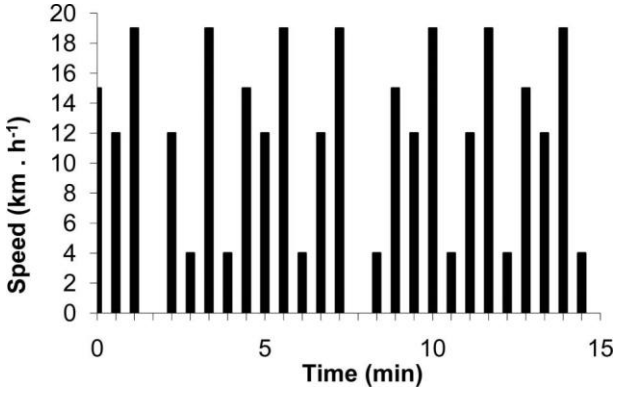

Figure 1. Activity profile of a single 15-min block of the soccer-specific protocol.

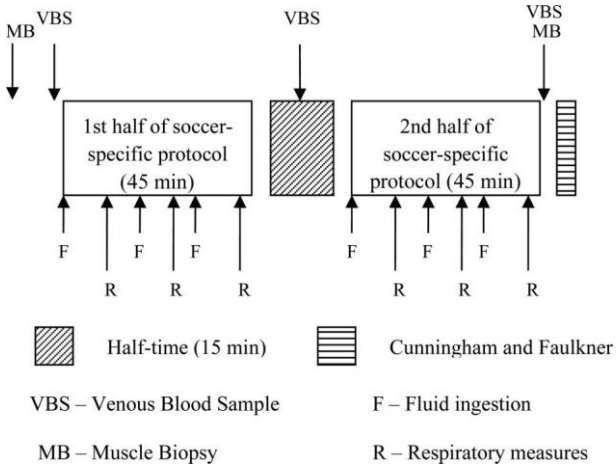

Figure 2. Schematic illustration of the experimental protocol.

completion of the protocol and a muscle biopsy was taken in order to assess muscle glycogen concentration post-exercise (Figure 2). After performing the soccer-specific protocol participants performed a test of exercise capacity to voluntary exhaustion. For the 3 days prior to the first test session, participants completed a diet and physical activity diary. This record was photocopied and returned to the participants to permit them to repeat their preparation for the remaining trials. During this period, mean energy (8.6+1.9 vs. 8.5+1.9 vs. 8.5+1.6 MJ day^{71};
$F_{2,22}$ ¼0.121; P¼0.887) and carbohydrate intake (377+40 vs. 375+41 vs. 383+39 g day^{71}; $F_{2,22}$ ¼1.920; P¼0.170) were similar between PLA, GLU and MIX respectively and there were no reported differences in the amount of physical activity.

Soccer-specific protocol

The soccer-specific protocol (Figure 2) was a modified version of that designed by Drust, Reilly, and Cable (2000) and reported in Clarke, Drust, Maclaren, and Reilly (2008). The full soccer-specific protocol consisted of 90 min activity divided into 26 45 min identical periods, separated by a period of 15 min, representing half-time. Each 45-min period consisted of three 15-min blocks. The protocol consisted of the various exercise intensities that are included during competitive soccer matches (i.e. walking, jogging, cruising and high-intensity running). 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 were as follows: static pauses

3.8% (0 km h^{71}); walking 27.9% (4 km h^{71}); jogging 38.9% (12 km h^{71}); cruising 19.9% (15 km h^{71}); high-intensity running 9.5% (19 km h^{71}). 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 the deduction of the total time taken for the changes in treadmill speed to be made were calculated. The duration of each discrete bout was as follows: static pauses 8.0 s; walking 27.8 s; jogging 38.7 s; cruising 34.8 s; high-intensity running 9.4 s.

Fluid ingestion

During one session 228 +6 ml (3 ml kg^{71} body mass) of carbohydrate-electrolyte solution (6.6 g 100 ml^{71} glucose syrup, maltodextrin, 49 mg 100 ml^{71} Na, 296 +1 mOsm kg^{71}, GlaxoSmithKline, UK) was consumed at 0, 15, 30, 45, 60 and 75 minutes of exercise (GLU) (Figure 2). On another occasion 228+7 ml of a glucose plus fructose solution (fructose, dextrose, maltodextrin; designed to provide a glucose-to-fructose ratio of 2:1) solution (6.6 g 100 ml^{71} fructose, dextrose, maltodextrin, 50 mg 100 ml^{71} Na, 313 +1 mOsm kg^{71}, GlaxoSmithKline, UK) was consumed at the same time points (MIX). During the remaining session 228+6 ml of a placebo (a similarly coloured, flavoured and textured electrolyte solution) (50.5 g 100 ml^{71} CHO, 49.5 mg 100 ml^{71} Na, 65+1 mOsm kg^{71}; GlaxoSmithKline, UK) was consumed (PLA). The total volume of fluid ingested during each trial was 1337 +124 ml. All solutions contained equal amounts of ascorbic acid, aspartame, acesulfame K, and vitamins (niacin, pantothenic acid, B6, B12). During the carbohydrate trials carbohydrate was ingested at a rate of 1+ 0 g min^{71} (60+1 g h^{71}). The trials were performed in a double-blind, counter-balanced fashion, although this was not fully possible due to the number of participants.

Physiological measurements

Oxygen consumption (V_ O_2) and carbon dioxide production (V_ CO_2) were recorded using an on-line automated gas analyser (Metalyzer3B, Cortex Biophysic GmbH, Germany) during a 2-min (10–12 min) period of each 15-min block, in order to assess substrate oxidation rates. The oxidation rates for carbohydrate and fat were calculated according to Frayn (1983). Each collection period consisted of a walk, a jog and high-intensity running and concluded with another walk. Thus, mean CO_2 expired during the collecting period reflected its production from O_2 consumed in the working tissue and as conditions were the same between participants and trials, so comparisons should be valid (Bangsbo, Nørregaard, & Thorsøe, 1992).

Venous blood samples (16 ml) were taken from an antecubital vein in the forearm. A blood sample was taken30 min before exercise commenced, at half-time and at the completion of the protocol. Blood samples were collected in serum separation tubes for insulin and IL-6, plastic tubes containing ethylenediaminetetraacetic acid (EDTA) for catecholamines, nonesterified fatty acids (NEFA)and glycerol, and lithium heparin tubes for glucose. All tubes were centrifuged and the plasma was frozen at7808C for analysis. Plasma samples were analysed for glucose (Glucose oxidase, Instrumentation Laboratory, Italy), lactate, glycerol (Randox Laboratories ltd, UK), NEFA (NEFA-C, Wako Chemicals GmbH, Germany), catecholamines (Catcombi ELISA, IBL GmbH, Germany),insulin (Insulin ELISA, DRG Instruments GmbH, Germany), IL-6 (IL-6 ELISA, BLK diagnostics, Spain) and epinephrine and norepinephrine (Catcombi ELISA, IBL GmbH, Germany). The changes in plasma volume were calculated according to the method of Dill and Costill (1974), and plasma osmolality was measured using an osmometer (Advanced Micro-osmometer Model 3300, Advanced Instruments inc, USA). The change in body mass was calculated from the difference in nude body mass between pre- and post-exercise and values were corrected for the volume of fluid ingested, respiratory losses (Mitchell, Nadel, & Stolwijk, 1972) and urine output to calculate sweat loss.

A percutaneous needle biopsy of vastus lateralis was obtained approximately one week before the first trial after an identical 3 day food intake as before each trial. This was in order to establish resting muscle glycogen levels. An additional biopsy was taken on completion of the soccer-specific protocol during each trial. After local anaesthesia [2 ml 0.5% Bupivacaine Hydrochloride (Marcain Polyamp, AstraZeneca, UK)] and incision of the skin and muscle fascia, percutaneous muscle

samples (*30 mg) were taken from the lateral vastus of the quadriceps femoris muscle using an automated procedure (Pro-Mag 2.2 Automatic Biopsy System, Manan Medical Products, USA) with a 14-gauge needle (ACN Biopsy needles, InterV, Denmark). The biopsy was immediately frozen in liquid nitrogen and stored at7808C for subsequent glycogen analysis. To determine the concentration of muscle glycogen the tissue was acid hydrolysed allowing the glucose residues to be measured enzymatically as described by Lowry and Passonneau (1972) and expressed as ‘‘wet weight’’.

Exercise capacity test

After completing the soccer-specific protocol, participants performed Cunningham and Faulkner's (1969) treadmill test in order to measure fatigue resistance to high-intensity exercise within the confines of the environmental chamber. The test required the participant to run at a gradient of 20% and a speed of 12.8 km h^{71} until fatigue. The time began when the participant started running unsupported and stopped when they grabbed the handrails at the point of fatigue. This test was a measure of fatigue resistance to high-intensity exercise and has been shown to be both valid and reliable as a measurement tool (Thomas, Plowman, & Looney,
2002). To assess reliability following familiarisation, the participants performed the Cunningham and Faulkner test on four occasions at least 3 days apart. There was no significant difference (P40.05) in time to exhaustion between trials. The coefficient of variation for time to exhaustion was 4.9%. Hence, the Cunningham and Faulkner test was deemed to provide a reliable measure of resistance to high intensity exercise. Furthermore, the smallest worthwhile effect was calculated to be 1.5% (1 s).

Statistical analysis

All variables were analysed using two-way analysis of variance (ANOVA) with repeated measures except for muscle glycogen concentration, sweat loss and the time to exhaustion during the Cunningham and Faulkner test, which were analysed using a one-way ANOVA with repeated measures. The smallest worthwhile effect was calculated in accordance with Hopkins, Hawley, and Burke (1999). Results are reported as the mean+the standard deviation (s) and a level of P50.05 was considered statistically significant.

Results

Muscle glycogen

Muscle glycogen concentration was significantly lower following the soccer-specific protocol compared with pre-exercise values in all trials ($F_{1,7}$ ¼ 7.14; P ¼0.021; Pre, 127.23+ 17.36 mmol kg wet $weight^{71}$; PLA, 62.99+8.39 mmol kg wet $weight^{71}$; GLU, 68.62+2.70 mmol kg wet $weight^{71}$ and MIX, 76.63+6.92 mmol kg wet $weight^{71}$). The difference between trials was not significant ($F_{2,8}$ ¼1.215; P ¼0.332) and the statistical power was 0.18.

Plasma metabolites

The concentration of plasma glucose (Figure 3a) was significantly higher in GLU compared with PLA throughout the protocol ($F_{2,16}$ ¼7.06; P ¼0.010) although no significant difference was observed between PLA and MIX (P ¼0.118) and GLU and MIX (P ¼1.000). Plasma glucose concentration

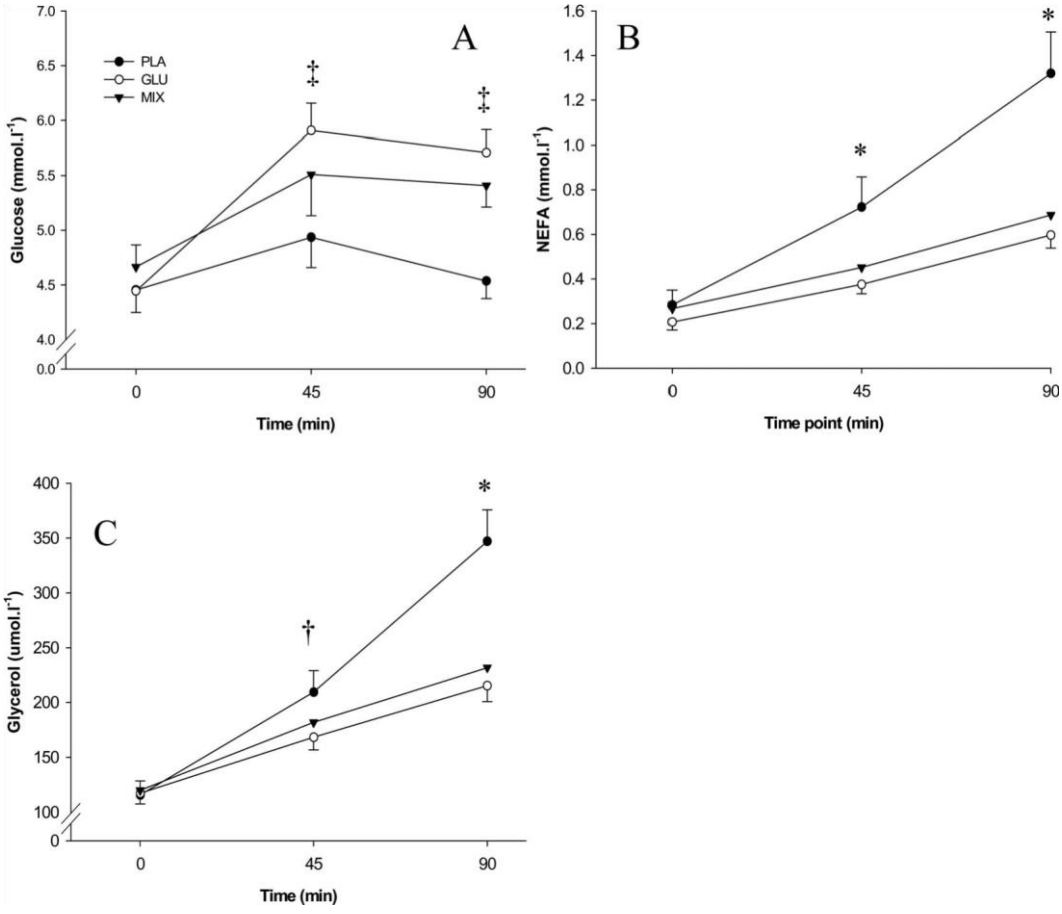

Figure 3. Plasma glucose (A), NEFA (B) and glycerol (C) concentrations during the soccer-specific protocol. { GLU significantly greater than PLA; * PLA significantly greater than GLU and MIX; { PLA significantly greater than GLU.

increased at the end of the first half in all trials, whereas during the second half plasma glucose was relatively constant during GLU and MIX, but decreased during PLA ($F_{2,24}$ ¼2.24; P¼0.012). In GLU and MIX, plasma glucose concentration was elevated significantly above resting levels at half-time and on completion of the soccer-specific protocol

($F_{2,17}$ ¼13.70; P 50.001).

The concentration of NEFA was significantly higher during PLA compared with GLU and MIX ($F_{1,13}$ ¼13.41; P ¼0.002; Figure 3b). The plasma NEFA concentration increased significantly as exercise progressed during all trials ($F_{1,13}$ ¼35.66; P50.001). After half-time NEFA concentration increased markedly more during PLA compared with GLU and MIX ($F_{2,18}$ ¼7.76; P ¼0.005). The concentration of glycerol (Figure 3c) was also significantly higher during the PLA trial compared with GLU throughout and significantly higher than MIX at 90 min ($F_{2,17}$ ¼12.47; P¼0.001). The glycerol concentration increased significantly between each time point in all trials ($F_{1,12}$ ¼61.75; P50.001). During the second half of the protocol, the glycerol concentration increased markedly more during PLA compared with GLU and MIX

($F_{2,22}$ ¼9.53; P ¼0.001).

Hormones

Epinephrine levels were similar between all trials ($F_{2,19}$ ¼0.84; P ¼0.446, Figure 4a) with values increasing significantly ($F_{1,11}$ ¼12.97; P¼0.004) throughout the protocol. A similar pattern was observed for norepinephrine (Figure 4b) with a significant increase throughout all trials ($F_{2,15}$ ¼ 73.117; P 50.001) with no differences between trials ($F_{2,15}$ ¼1.341; P ¼0.284). The insulin concentration was significantly higher during GLU and MIX than during the PLA condition ($F_{2,16}$ ¼12.25; P50.001; Figure 4c), and increased during the first half for GLU and MIX, whereas it decreased during PLA ($F_{2,24}$ ¼4.08; P¼0.024). All trials demonstrated a reduced insulin response during the second half. During the first 45 min of the protocol, IL-6 concentration (Figure 4d) increased significantly more during PLA compared with GLU and MIX ($F_{2,17}$ ¼16.31; P 50.001). Although the increase

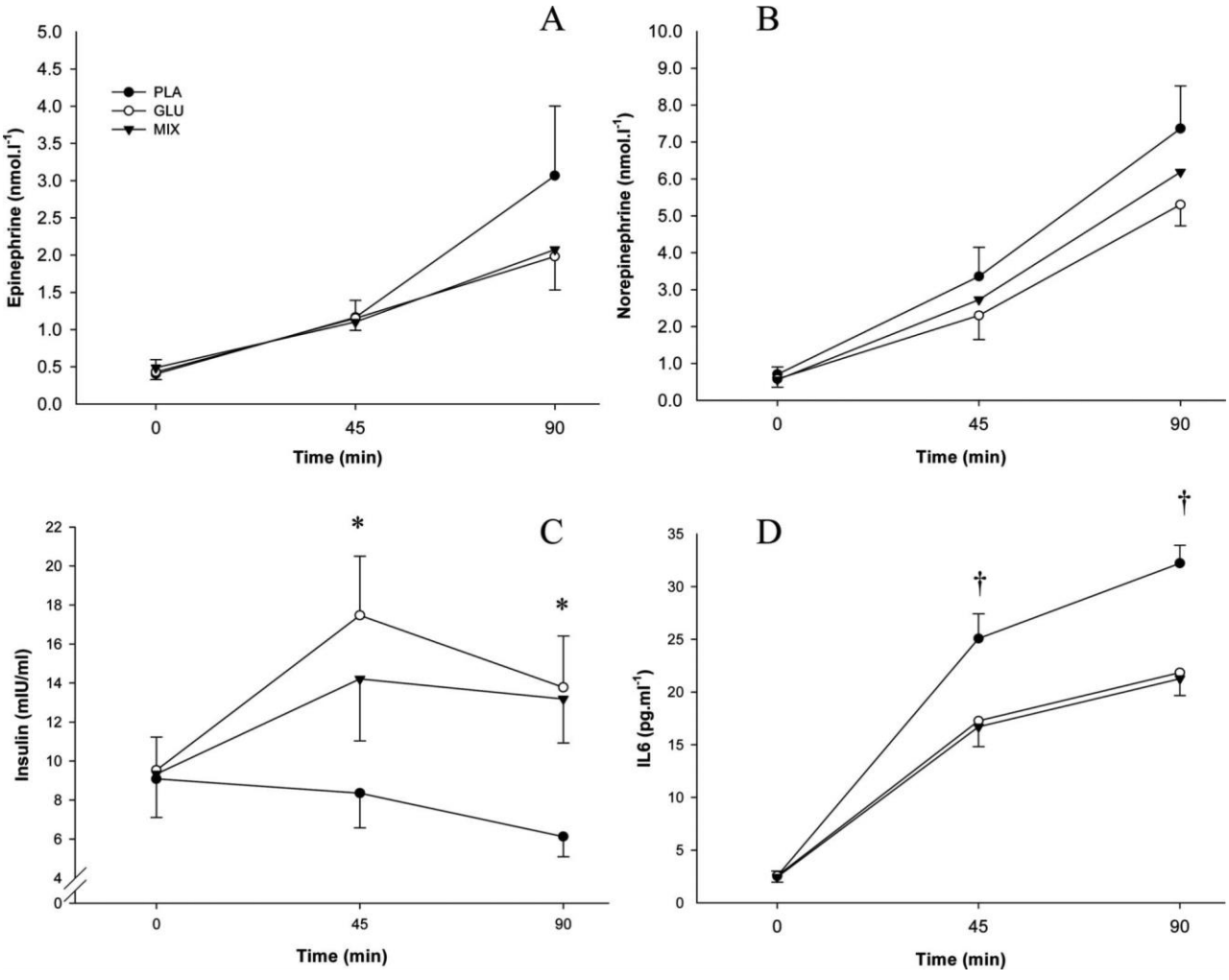

Figure 4. Epinephrine (A), norepinephrine (B), insulin (C) and IL-6 concentrations during the soccer-specific protocol. * GLU and MIX significantly higher than PLA. { PLA significantly greater than GLU and MIX.

was less pronounced during the second 45 min ($F_{3,28}$ ¼8.80; P50.001).

Substrate oxidation

The rate of total carbohydrate oxidation (Figure 5a) was significantly greater during MIX compared to PLA ($F_{2,20}$ ¼3.56; P ¼0.039). There were no significant differences between MIX and GLU (P¼1.000) or GLU and PLA (P¼0.210). Rate of carbohydrate oxidation remained relatively constant throughout the protocol during GLU and MIX though declined steadily in contrast during PLA ($F_{4,37}$ ¼3.80; P¼0.013). The rate of fat oxidation (Figure 5b) during PLA was significantly higher than MIX ($F_{2,19}$ ¼4.11; P ¼0.035) although there was no significant difference between GLU and MIX (P¼1.000) or PLA and GLU (P ¼0.240). The rate of fat oxidation increased steadily during PLA in contrast with the carbohydrate trials, where the rate of fat oxidation was relatively constant after an initial increase ($F_{3,31}$ ¼4.44; P¼0.010).

Plasma volume changes and sweat loss

There were no significant differences in plasma volume changes ($F_{2,18}$ ¼0.873; P ¼0.390) or plasma osmolality ($F_{1,14}$ ¼0.011; P ¼0.963) between the three experimental conditions (Table I). The percentage of body mass lost was not significantly different between the three trials (PLA: 1.35+0.03%; GLU: 1.35+0.04% and MIX:

1.35+0.04%; $F_{2,20}$ ¼0.557; P ¼0.581).

Exercise capacity

There was no significant effect of treatment on exercise capacity PLA: 73.62+8.61 s; GLU: 77.11+7.17 s; MIX: 83.04+9.65 s ($F_{2,16}$ ¼1.98; P¼0.060). However the improvements with GLU and MIX were both greater than the calculated smallest worthwhile difference. The individual responses are presented in Figure 6 and for the majority of participants an improvement in their exercise capacity was observed during GLU and

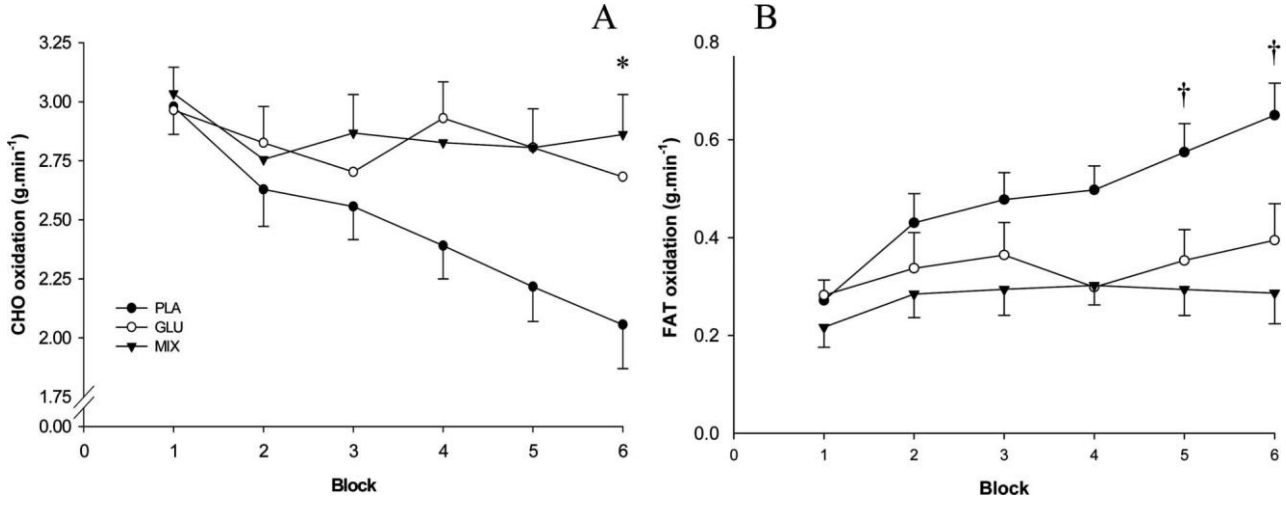

Figure 5. Carbohydrate (A) and fat (B) oxidation during the soccer-specific protocol. *MIX significantly higher than PLA. { PLA
Significantly higher than MIX.

Table I. Changes in plasma volume and osmolality during the soccer-specific protocol.

	Plasma volume change		Plasma osmolality ($mOsmkg^{71}$)		
	45 min	90 min	0 min	45 min	90 min
PLA	72.4+1.5%	73.3+1.8%	295+1	301+3	302+4
GLU	72.1+0.9%	73.2+1.9%	296+2	300+3	303+4
MIX	72.2+1.1%	73.2+1.6%	296+2	301+4	303+3

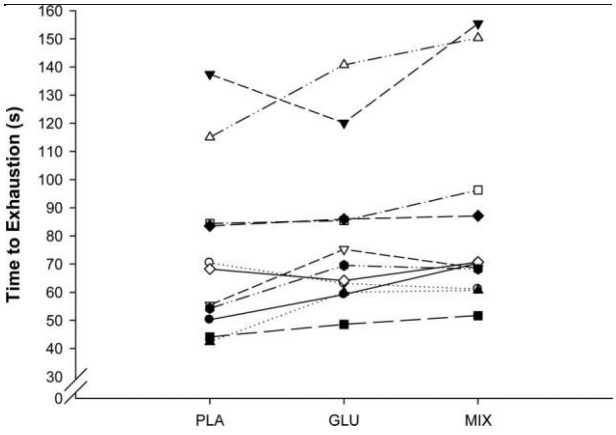

Figure 6. Individual responses to the Cunningham and Faulkner test.

MIX compared with PLA, and for eight (73%) participants MIX was greater than GLU.

Discussion

The major findings of this study were that, when compared to a solution containing only glucose, the ingestion of a solution containing glucose plus fructose did not significantly alter muscle glycogen concentration post-exercise or the rate of total carbohydrate oxidation during simulated soccer match-play. Exercise capacity, following the 90 min of activity, was also not significantly affected by the composition of fluid consumed. These findings suggest that when ingesting carbohydrate at moderate rates, the manipulation of the carbohydrate formulation does not significantly impact on either exercise capacity or metabolism in this pattern of exercise.

One possible benefit of ingesting a glucose plus fructose solution is that it increases the availability of exogenous carbohydrate and subsequent oxidation, thereby potentially sparing muscle glycogen. The ingestion of MIX significantly enhanced the rate of total carbohydrate oxidation when compared with PLA towards the completion of the soccer-specific protocol although there were no differences between
GLU and MIX or GLU and PLA. However, this finding may have been related to the low statistical power of the test (0.59). Furthermore, muscle glycogen levels were not significantly different after

completing the protocol. These results would suggest that under these conditions the ingestion of carbohydrate at moderate rates, either as MIX or GLU, does not appear to influence muscle glycogen utilisation. The ingestion of high concentration (1.5–2.4 g min^{71}) multi-carbohydrate solutions has previously been reported to decrease endogenous carbohydrate oxidation, suggesting a reduction in muscle glycogen utilisation in thermoneutral temperatures (Jentjens et al., 2004a; Jentjens et al., 2004c) and in the heat (Jentjens et al., 2006). However, these studies have employed relatively low intensity cycling protocols that do not reflect the workload associated with soccer. Furthermore, the ingestion of a single carbohydrate at high rates is not recommended for prolonged exercise (Jeukendrup, 2008) as there is an increased risk of gastrointestinal discomfort (Jentjens et al., 2006; Wallis, Rowlands, Shaw, Jentjens, & Jeukendrup, 2005).

When ingested at a rate of 1.8 g min^{71}, Wallis et al. (2005) reported the ingestion of carbohydrate significantly suppressed endogenous carbohydrate oxidation. However, there was no significant difference in the contribution of endogenous carbohydrate oxidation between maltodextrin and an isoenergetic drink containing maltodextrin plus fructose. This observation reflects the similar muscle glycogen concentrations between GLU and MIX in the present study. Therefore, the results from the present study support the previous findings of Wallis et al. (2005) and Hulston, Wallis, and Jeukendrup (2009) that when ingested at moderate rates, solutions containing glucose plus fructose are equally effective as those containing only glucose at sparing endogenous carbohydrate during exercise. However, these finding may be expected as exogenous carbohydrate oxidation is primarily limited by the saturation of intestinal glucose transporters and intestinal absorption when ingested at high rates (41 g min^{71}) (Jeukendrup, 2008).

Carbohydrate ingestion has also been demonstrated to alter carbohydrate oxidation (Clarke, Drust, MacLaren, & Reilly, 2005; Clarke et al., 2008; Coyle et al., 1983; Nicholas et al., 1995). Irrespective of type, carbohydrate ingestion succeeded in altering oxidation rates during soccer-specific intermittent exercise, noted by the observation of a significant interaction between condition and time. The ingestion of carbohydrate resulted in increased plasma glucose levels and reduced fat oxidation and NEFA and glycerol concentrations. The elevated plasma glucose levels after carbohydrate ingestion increased insulin concentration and reduced whole-body lipolysis, as indicated by the lower fat oxidation, and reduced levels of NEFA and glycerol during the GLU and MIX trials. These changes are a consequence of the role of insulin as an inhibitor of lipolysis and thereby the appearance of NEFA in the blood (Horowitz, Mora-Rodriguez, Byerley, & Coyle, 1997).

In the present study the lack of statistical difference in exercise capacity between any of the trials may have been as a consequence of the similar muscle glycogen concentrations at the end of the 90 min simulations. This is similar to the data of Morris et al. (2003) who failed to show any benefit of carbohydrate ingestion in the heat. However, the low statistical power of the test (0.36) may have also contributed to this finding as the data demonstrates improved exercise capacity of 8% during GLU and 17% during MIX compared with PLA. There was also an 8% improvement in exercise capacity during MIX compared with GLU. Furthermore, it has been suggested that a change of approximately 0.3 of the within-participant variability in performance between competitions is probably worthwhile for sports performance contexts (Hopkins et al., 1999). Therefore based on the reliability and familiarisation data an improvement of 1 s would be beneficial on a practical level. As a consequence it could be suggested that glucose ingestion may be beneficial for intermittent exercise performance in the heat. Furthermore, a glucose plus fructose solution could enhance this further, possibly due to the ingestion of carbohydrate enabling a higher rate of carbohydrate oxidation to be maintained during exercise. However, further study is required to establish whether this

translates to improvements in soccer performance in actual matches. Furthermore, despite a 6% fructose only solution previously being associated with gastrointestinal distress, compromised physiological response and reduced exercise capacity (Murray, Paul, Seifert, Eddy, & Halaby, 1989), it would have been interesting to have performed an additional ‘‘fructose-only’’ trial. This would have allowed exploration of the two main effects fructose vs. PLA and glucose vs. PLA and the interaction between the main effects (MIX).

In the present study plasma volume changes, plasma osmolality, weight loss and sweat loss were not significantly different between treatments. These findings may suggest that there was no significant difference in the amount of water absorbed from the intestine between the different types of drink. This finding is similar to that of Hulston et al. (2009), who reported that plasma deuterium enrichment, a marker of fluid availability from ingested beverages, was similar for glucose and glucose plus fructose solutions. Previous studies (Davis et al., 1990; Jentjens et al., 2006) have, however, indicated that fluid availability during exercise in the heat is lower with a glucose drink compared with a combined glucose and fructose drink as a consequence of greater water absorption due to increased total solute absorption (Shi et al., 1995). This effect may have been a consequence of the higher carbohydrate concentrations ingested in comparison with those in the present study (1.5 g min^{71} vs. 1 g min^{71} carbohydrate). Therefore, during exercise of this nature, when a carbohydrate solution is ingested during exercise in the volume and concentration used here, the addition of more than one type of carbohydrate to the solution may not significantly increase water absorption from the intestine and influence the availability of water from the ingested solution. Furthermore, a relatively dilute carbohydrate solution may be as effective as water for replacing fluid losses during soccer-specific exercise in the heat.

Conclusion

In conclusion, when ingested in moderate (practical) concentrations (1 g min^{71}), altering the carbohydrate composition does not significantly influence metabolism during intermittent exercise that corresponds to the intensity of a soccer match, or physical capacity at the end of an intermittent exercise protocol performed in the heat. However, when compared with the placebo, the glucose plus fructose solution increased total carbohydrate oxidation during exercise. On a practical level the data suggests that carbohydrate ingestion may be beneficial for exercise capacity in the heat. It could be suggested that glucose ingestion may improve exercise capacity and a glucose plus fructose solution could enhance performance further. However, due to the limitations of a low statistical power, a not fully counterbalanced trial as a consequence of 11 participants and the absence of true baseline muscle glycogen values for each trial, further study is required to substantiate the smallest worthwhile effect regarding the potential performance benefits of both carbohydrate formulations.

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