Journal of Sports Sciences

Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713721847

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First published on: 04 December 2009

To cite this Article Ali, Ajmol and Williams, Clyde(2009) 'Carbohydrate ingestion and soccer skill performance during prolonged intermittent exercise', Journal of Sports Sciences, 27: 14, 1499 — 1508, First published on: 04 December 2009 (iFirst)

To link to this Article: DOI: 10.1080/02640410903334772

URL: http://dx.doi.org/10.1080/02640410903334772

Journal of Sports Sciences, December 2009; 27(14): 1499–1508

Carbohydrate ingestion and soccer skill performance during prolonged intermittent exercise

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(Accepted 14 September 2009)

Abstract

The aim of this study was to investigate the effect of ingesting a carbohydrate-electrolyte solution, during the 90-min Loughborough Intermittent Shuttle Test, on soccer skill performance. Seventeen male soccer players ingested either a 6.4% carbohydrate-electrolyte solution or placebo solution equivalent to 8 ml · kg^{-1} body mass before exercise and 3 ml · kg^{-1} body mass after every 15 min of exercise, in a double-blind randomized cross-over design, with the trials separated by 7 days. The evening before the main trial, the participants performed glycogen-reducing exercise on a cycle ergometer (80 min at 70% $\dot{V}O_{2max}$) and were then fed a low-carbohydrate meal. After a 12-h overnight fast, they performed The Loughborough Soccer Passing Test before and after every 15 min of exercise. Analysis of the combined skill test data showed a significant time effect ($P = 0.001$) with differences between 0–45 and 75–90 min ($P < 0.05$). There was a 3% reduction in skill performance from before to after exercise in the carbohydrate-electrolyte trial, whereas in the placebo trial the decrease was 14% ($P = 0.07$). In conclusion, skill performance during the simulated soccer activity appeared to deteriorate in the last 15–30 min of exercise. However, providing 52 g · h^{-1} carbohydrate during exercise showed a tendency to better maintain soccer skill performance than a taste-matched placebo.

Keywords: *Fluid ingestion, football, Loughborough Intermittent Shuttle Test, Loughborough Soccer Passing Test, sprint performance*

Introduction

There is limited information on the effects of fatigue on soccer skill performance. This is surprising because the skill elements are essential in producing successful outcomes – that is, winning games (Reilly, 1996). In a previous study, we found that soccer dribbling performance deteriorated following 90 min of intermittent high-intensity shuttle-running exercise in the absence of fluids (McGregor, Nicholas, Lakomy, & Williams, 1999). Furthermore, Ostojic and Mazic (2002) reported a 5% improvement in soccer dribbling performance following carbohydrate supplementation during a 90-min exhibition match. However, as in this latter study there were no baseline measures of skill performance, it cannot be assumed that the players were as skilful as each other when they began the match. Nevertheless, we have recently shown that when players ingested a carbohydrate-electrolyte solution they maintained soccer shooting performance and that there was also a tendency to maintain passing skill performance (Ali, Williams, Nicholas, & Foskett, 2007b). However, using a pre- and post-trial experimental design provides no indication as to *when* the decrement in skill occurred (e.g. gradual decline over the duration of the activity/match or a sudden decline at the end of the exercise).

Soccer involves the application of three types of skill: motor, perceptual, and cognitive (Bate, 1996). However, it is the latter that has been researched most with regard to the influence of exercise. For example, McMorris and Graydon (1997) reported that exercise increased physiological arousal and facilitated cognitive performance in experienced soccer players, with the best results being obtained following maximal exercise. However, this view is at odds with Easterbrook's (1959) "Cue Utilization Theory", which states that moderate arousal should be optimal for cognitive performance. A subsequent study concentrated specifically on the "motor" aspect of soccer skill performance and the influence

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ISSN 0264-0414 print/ISSN 1466-447X online
DOI: 10.1080/02640410903334772

of carbohydrate ingestion (Northcott, Kenward, Purnell, & McMorris, 1999): participants were required to perform 10-, 20-, and 30-m passes and a 15-m shooting task after every 15 min of intermittent running. For each skill element, error was dependent on the distance from a specified target. In the placebo condition, performance improved from baseline up to 60 min of exercise and then returned to resting values after the 90 min of intermittent exercise. However, in the carbohydrate trial, all activity "skill" test scores were better than baseline values.

Although some closed skills operate during soccer match-play (e.g. free kicks and corner kicks), most play involves open skills (Knapp, 1977). For that reason, isolating one aspect of the game, for example passing or shooting from a static play (Northcott et al., 1999), may make it an execution of "technique" rather than "skill" *per se* (Ali et al., 2007a). Furthermore, soccer requires the application of cognitive, perceptual, and motor skill, operating simultaneously in a rapidly changing environment (Bate, 1996). Therefore, examining just one aspect, such as cognitive skill (McMorris and Graydon, 1997), is not holistic. Thus, the recently developed Loughborough Soccer Passing Test offers the opportunity for researchers to assess the multi-faceted aspects of soccer skill within a dynamic context (Ali et al., 2007a). More specifically, players need to respond to the investigator's call, use memory and perception to figure out the next pass in the sequence, and then perform the motor tasks of dribbling, controlling, and passing the ball against coloured target areas. Therefore, the Loughborough Soccer Passing Test is a holistic test that requires application of all three aspects of skilful performance (Bate, 1996).

The contribution of anaerobic metabolism to energy provision is essential during soccer, as the performance of skilful actions requires quick and powerful movements. It has been suggested that muscle glycogen concentrations must fall below a critical threshold of about 175 mmol · kg^{-1} dry weight for high-intensity exercise to be seriously affected (Jacobs, 1981). We have previously reported muscle glycogen concentrations of 170 mmol · kg^{-1} dry weight following 90 min of the Loughborough Intermittent Shuttle Test (Nicholas, Tsintzas, Boobis, & Williams, 1999). However, the muscle glycogen concentrations were not reduced below 170 mmol · kg^{-1} dry weight for all participants and so we cannot state whether low carbohydrate stores had a significant impact on skill performance. Thus, reducing muscle glycogen concentrations before the start of exercise may help identify more clearly the possible impact of the exogenous carbohydrate–electrolyte solution on skill performance. Thus in our previous study (Ali et al., 2007b) we used glycogen-depleted fasted soccer players in a study on the influence of ingesting a carbohydrate-electrolyte solution on passing skill performance before and after completion of the 90-min Loughborough Intermittent Shuttle Test. The soccer players consumed either a carbohydrate-electrolyte solution or taste-matched placebo before and throughout the 90 min. There was a strong trend towards a greater retention of passing skill performance following the ingestion of the carbohydrate-electrolyte than after the ingestion of the placebo solution (Ali et al., 2007b). These results raised questions about the amount of carbohydrate ingested and whether passing skill performance decreased gradually throughout the 90 min of exercise or occurred in the final minutes of the test. Indeed, a review of the literature suggests an exogenous supply of 50 g · h^{-1} may be required to impact on motor skill performance (Graydon, Taylor, & Smith, 1998; Northcott et al., 1999; Welsh, Davis, Burke, & Williams, 2002).

The main aim of the present study was to examine the time course of soccer skill decrement *during* 90 min of simulated soccer activity. A further aim was to examine the influence of ingesting a carbohydrate-electrolyte (52 g · h^{-1}) solution on soccer skill performance.

Methods

Participants

Seventeen healthy male soccer players (age: 20.9 ± 2.5 years; height: 1.74 ± 0.05 m; body mass: 71.5 ± 5.4 kg; $\dot{V}O_{2max}$: 59.0 ± 3.1 ml · kg^{-1} · min^{-1}; mean ± *s*) volunteered to participate in the study. The participants were semi-professional or ex-professional players from university teams. They were from a range of outfield playing positions and were involved in regular training and match-play. All procedures had the prior approval of Loughborough University's Ethics Advisory Committee. After completion of a health screening questionnaire, written informed consent was obtained from all participants.

Preliminary measurements

Participants reported to the laboratory on two separate occasions for preliminary measurements. During the first session, physiological measurements (height and body mass) were performed, and maximal oxygen uptake ($\dot{V}O_{2max}$) was estimated by means of the "Progressive Multistage Fitness Shuttle Run Test" (Ramsbottom, Brewer, & Williams, 1988). Participants were also familiarized with the skill test (Loughborough Soccer Passing Test; Ali et al., 2007a) and the prolonged intermittent high-intensity shuttle-running protocol (Loughborough Intermittent Shuttle Test; Nicholas, Nuttall, & Williams, 2000) during both sessions.

Experimental procedures

Participants completed two main trials, each separated by at least 7 days. The order of trials was randomized to counteract order effects. Participants were asked to record their food and drink consumption for the 2 days prior to the first of the main trials and to replicate their intake before the second main trial. During this time, mean energy (11.2 ± 2.4 vs. 11.3 ± 3.1 MJ · day^{-1}) and carbohydrate intake (396 ± 107 vs. 382 ± 133 g · day^{-1}) were similar between carbohydrate-electrolyte and placebo trails. Each main trial took place over 2 days (Figure 1). On the first day, the participants reported to the laboratory at 17:00 h and performed a prolonged bout of exercise on a cycle ergometer to reduce their muscle glycogen stores using a procedure originally designed for this purpose by Vollestad and colleagues (Vollestad, Tabata, & Medbo, 1992) and confirmed by Bowtell et al. (1999). This procedure required the participants to cycle for 30 min at 70% $\dot{V}O_{2max}$, followed by three 50-s "sprints" at double the resistive load (with 2 min rest between sprints), and then another 45 min at 70% $\dot{V}O_{2max}$. After completing this exercise, the participants were provided with a low-carbohydrate meal at approximately 20:00 h, which was the last meal of the day (energy content of 56 kJ · kg^{-1} body mass and carbohydrate content of 1 g · kg^{-1} body mass). They were instructed not to consume any other food following this meal, but were allowed to consume water *ad libitum*. Following this procedure, the participants arrived in the laboratory the following morning having fasted for 12 h.

Upon arrival on the morning of day 2, each participant's nude body mass was determined and then a cannula was inserted into a forearm vein while he lay on an examination couch. After the cannulation procedure was completed, the participants stood for 10 min before resting blood and expired air samples were collected. After a standardized 10-min warm-up, they performed the pre-exercise (0 min) skill test and then drank one of the test solutions. In the carbohydrate trial, the participants were provided with a commercially available sports drink containing 6.4% carbohydrate (Lucozade Sport^{TM}). In the other trial, they drank a non-electrolyte, artificially sweetened placebo that contained no carbohydrate. The artificial sweeteners, present in both solutions, were aspartame and acesulfame K. The two solutions looked and tasted the same, had the same mouth feel, and were manufactured by the same company

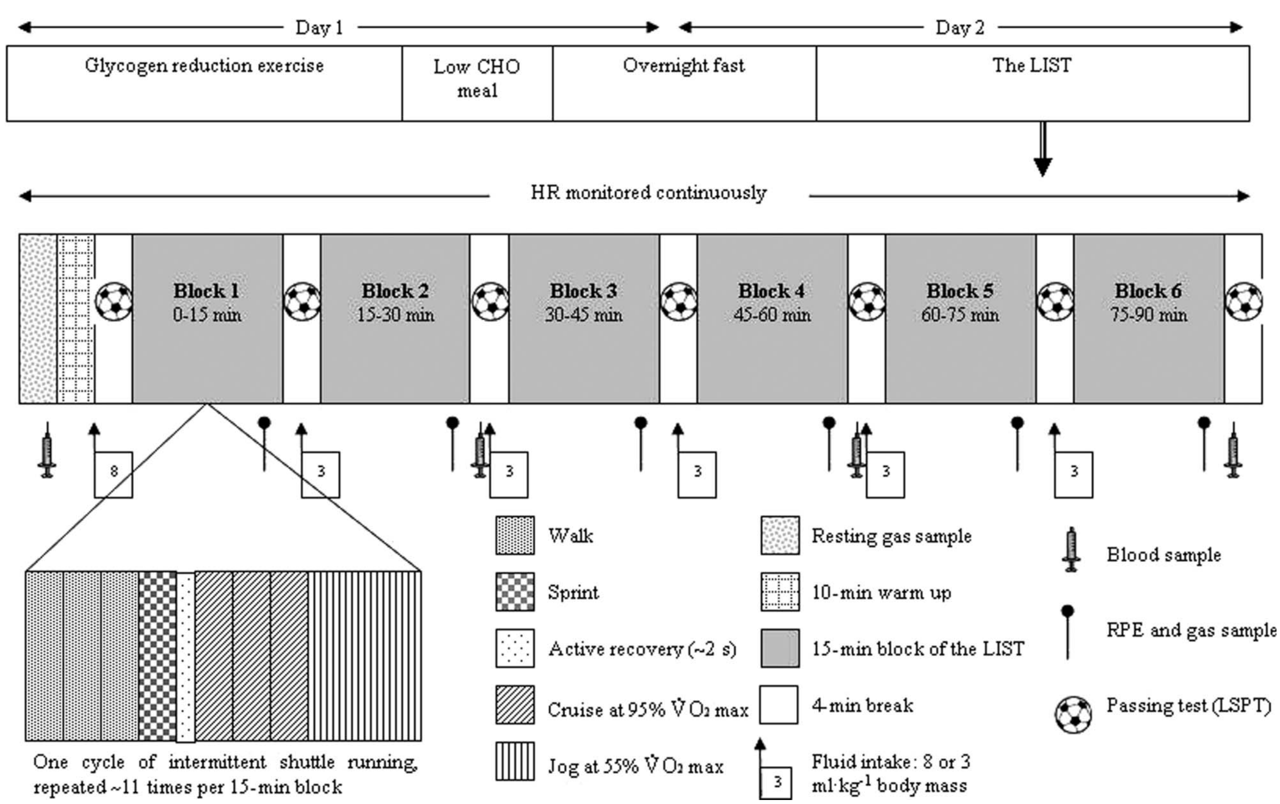

Figure 1. Schematic representation of the experimental protocol and the Loughborough Intermittent Shuttle Test (LIST). CHO = carbohydrate.

(GlaxoSmithKline, Brentford, UK). Before commencing the soccer simulation exercise, the participants ingested a volume of fluid equivalent to 8 ml $\cdot$ kg^{-1} body mass and then 3 ml $\cdot$ kg^{-1} body mass after every 15 min of exercise. This drinking regime enabled the participants to ingest approximately 800 ml $\cdot$ h^{-1} fluid and 52 g $\cdot$ h^{-1} carbohydrate. In a post-study interview, the participants were asked to try and identify which of the solutions they had ingested in the two trials and their responses showed quite clearly that they were unaware of the order of treatments.

After ingesting the test solution, the participants completed six 15-min blocks of the Loughborough Intermittent Shuttle Test punctuated by 4-min rest periods. Each 15-min block consists of approximately 11 repeated cycles of walking, running (at a speed equivalent to 95% $\dot{V}O_{2max}$), jogging (at a speed equivalent to 55% $\dot{V}O_{2max}$), and sprinting (for more specific details, see Nicholas et al., 2000). During the rest periods, the participants ingested the equivalent of 3 ml $\cdot$ kg^{-1} body mass of the same drink and performed the Loughborough Soccer Passing Test. The skill test requires participants to complete 16 passes against coloured targets, whilst manoeuvring around a grid of cones and lines, as quickly as possible. Performance comprises time to complete the passes plus any additional penalty time for inaccurate passing or poor control of the ball (for more details, see Ali et al., 2007a). Expired air was collected, using the modified Douglas bag method, for the determination of oxygen uptake and estimation of energy expenditure (via indirect calorimetry), during the ninth cycle of each block of exercise. Ratings of perceived exertion (Borg, 1973) and environmental temperature were measured on the last walk phase of each block of exercise. Heart rate was monitored continuously throughout exercise via short-range telemetry (Vantage NV, Polar, Finland). The participants were constantly encouraged to maintain the pace set by the audio signals and to perform maximally during the sprints. After completing the soccer simulation exercise, the participants performed the post-exercise (90 min) skill test. Nude body mass was determined following the post-exercise skill tests after the participants had towel-dried themselves to remove excess sweat.

Blood analyses

Blood samples were drawn from an indwelling venous cannula, in volumes of 10 ml, at rest and after 30, 60, and 90 min of exercise. All blood collection procedures were performed as described in previous studies from this laboratory (McGregor et al., 1999). Changes in plasma volume were determined using haematocrit values and haemoglobin concentrations (Dill & Costill, 1974); plasma samples were analysed for glucose, lactate, and free fatty acid concentrations and serum samples for insulin using methods described previously (McGregor et al., 1999; Nicholas et al., 1999).

Statistical analyses

The data were examined using a two-factor (drink treatment $\times$ time of measurement) analysis of variance (ANOVA), with repeated measures for correlated data (SPSS, version 14.0). When differences were found by ANOVA, paired Student's *t*-tests with the Bonferroni adjustment were used to ascertain where the differences lay. Paired Student's *t*-test was also used to examine differences in skill performance between trials. Data are presented as means $\pm$ standard deviations (*s*). Statistical significance was set at $P < 0.05$.

Results

Two-way analysis of variance and/or paired Student's *t*-tests were performed on all Trial 1 vs. Trial 2 data. There were no significant differences between trials (i.e. trial order effect), thus any differences between conditions are likely to be due to treatment effects. All participants ($n = 17$) were able to complete the pre-test prolonged cycling bout, the 90-min Loughborough Intermittent Shuttle Test, and skill tests for both the carbohydrate-electrolyte and placebo trials. However, blood samples were obtained from only 10 participants because the remaining seven opted out of the blood sampling phase of the study. Therefore, the data relating to blood variables are based on only 10 participants (note that the power analyses were based on 17 participants for the performance data and do not apply to blood variables).

Performance data

Soccer skill test performance time is a combination of time taken to complete each test and penalty time accrued for inaccurate passing or poor control. Table I shows that there was no difference in the movement time between treatments or at various instances during exercise. There were no differences between carbohydrate-electrolyte and placebo trials but penalty time increased with duration of exercise (time effect, $P = 0.002$; Table I). Examination of the pre- and post-exercise results (i.e. 0 min vs. 90 min) showed a $3 \pm 12\%$ decrease in performance in the carbohydrate-electrolyte trial but a $14 \pm 24\%$ decrease in the placebo trial, although this was not statistically significant [$P = 0.07$; Cohen's $d = 0.53$ (medium)]. Although there were no differences in

Table I. Movement time, penalty time, and total performance time during the Loughborough Intermittent Shuttle Test (LIST) in the carbohydrate-electrolyte (CHO-E) and placebo (PLA) trials (mean $\pm$ *s*; $n = 17$).

	Exercise time during the LIST (min)						
	0	15	30	45	60	75	90
Movement time (s)							
CHO-E	37.4 ± 2.0	37.3 ± 2.5	37.4 ± 2.5	37.5 ± 2.7	37.6 ± 2.1	37.9 ± 3.0	37.6 ± 1.9
PLA	36.9 ± 2.6	37.1 ± 2.4	37.1 ± 2.2	37.4 ± 3.0	37.7 ± 3.3	38.0 ± 3.6	38.3 ± 4.2
Penalty time (s)							
CHO-E	4.3 ± 4.1	1.5 ± 5.5	3.4 ± 7.8	3.5 ± 5.1	4.5 ± 5.5	6.4 ± 6.8	5.2 ± 6.0
PLA	2.3 ± 4.5	2.2 ± 6.1	2.1 ± 6.9	1.4 ± 5.2	2.5 ± 7.5	7.2 ± 5.4	5.9 ± 5.9
Total performance time (s)							
CHO-E	41.6 ± 4.6	38.8 ± 6.0	40.8 ± 8.2	40.9 ± 5.0	42.2 ± 5.8	44.3 ± 7.8	42.8 ± 6.0
PLA	39.2 ± 5.4	39.3 ± 7.5	39.2 ± 7.6	38.8 ± 6.3	40.1 ± 9.1	45.2 ± 7.2	44.2 ± 7.8

overall performance between treatments, a significant time effect was observed ($P = 0.001$; Figure 2); *post-hoc* analyses revealed significant differences between 0–45 min and 75–90 min ($P < 0.05$).

Mean 15-m sprint times increased with duration of exercise. More specifically, performance was significantly slower during the last 30 min than the first 30 min of exercise (main effect of time, 2.62 s vs. 2.72 s, block 1–2 vs. block 5–6; $P < 0.05$). Although not statistically significant, there was a trend for performance to be better maintained in the carbohydrate-electrolyte trial in the last block of exercise, whereas there was a trend for a further decrease in performance during the placebo trial (2.70 $\pm$ 0.12 s vs. 2.76 $\pm$ 0.16 s, carbohydrate-electrolyte vs. placebo; $P = 0.15$) (Figure 3).

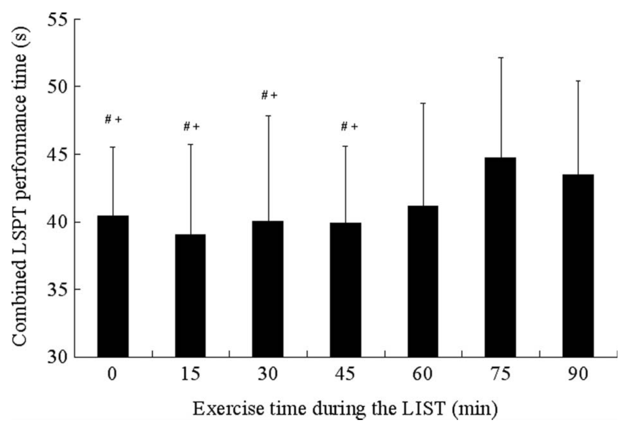

Figure 2. Combined Loughborough Soccer Passing Test (LSPT) performance times during the Loughborough Intermittent Shuttle Test (LIST). #Significantly different from 75 min, $P < 0.05$. +Significantly different from 90 min, $P < 0.05$.

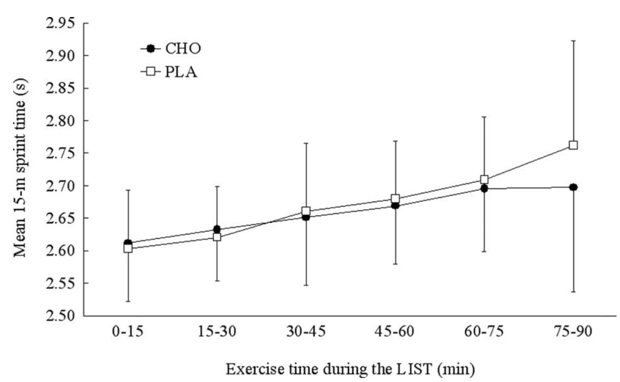

Figure 3. Mean 15-m sprint time (s) per block of the Loughborough Intermittent Shuttle Test (LIST) in the carbohydrate-electrolyte (CHO-E) and placebo (PLA) trials ($n = 17$).

Physiological data

Although heart rate appeared to be 2–4 beats $\cdot$ min^{-1} higher for each block of exercise in the carbohydrate-electrolyte trial, there was no significant difference between trials. However, there was a main effect of time and, as expected, heart rates were lower in block 1 than blocks 2–5 (152 $\pm$ 7 beats $\cdot$ min^{-1} vs. 156 $\pm$ 7 beats $\cdot$ min^{-1}, block 1 vs. blocks 2–5; $P < 0.05$). Oxygen uptake increased from block 1 to block 3 but then decreased again to block 6 (main effect of time: 44.5 $\pm$ 5.1 ml $\cdot$ kg^{-1} $\cdot$ min^{-1} vs. 46.6 $\pm$ 3.0 ml $\cdot$ kg^{-1} $\cdot$ min^{-1} vs. 44.9 $\pm$ 3.7 ml $\cdot$ kg^{-1} $\cdot$ min^{-1}, block 1 vs. block 3 vs. block 6; $P < 0.05$). After 60 min of exercise, oxygen uptake in the carbohydrate-electrolyte trial ($\sim$46 ml $\cdot$ kg^{-1} $\cdot$ min^{-1}) was maintained, whereas there was a further decrease in the placebo trial ($<$44 ml $\cdot$ kg^{-1} $\cdot$ min^{-1}; Table II), but this was result was not statistically significant. The relative exercise intensity, expressed in terms of $\%\dot{V}O_{2max}$, showed similar results to oxygen uptake. There was a main effect of time, with an initial increase from the start of exercise to block 3 and then a drop to block 6 (76 $\pm$ 9% vs. 79 $\pm$ 6% vs. 76 $\pm$ 7%, block 1 vs. block 3 vs. block 6; $P < 0.05$). Even though there was a 4% difference between trials in the last 15 min of exercise, there was no statistically significant treatment or interaction effect (Table II).

Table II. Oxygen uptake ($\dot{V}O_2$), relative exercise intensity (%$\dot{V}O_{2max}$), oxidation rates of carbohydrate and fat, and energy expenditure at rest, during each 15-min block, and overall mean of the Loughborough Intermittent Shuttle Test (LIST) in the carbohydrate-electrolyte (CHO-E) and placebo (PLA) trials (mean ± *s*; *n* = 17).

	Rest	Exercise time during the LIST (min)						Mean of trial
		0–15	15–30	30–45	45–60	60–75	75–90	
$\dot{V}O_2$ (ml · kg^{-1} · min^{-1})								
CHO-E	5.5 ± 0.9	44.1 ± 4.1	45.4 ± 5.0	47.0 ± 2.9	46.1 ± 45.8	45.8 ± 2.9	45.9 ± 3.5	45.7 ± 3.7
PLA	5.2 ± 0.5	44.9 ± 6.0	46.7 ± 3.6	46.2 ± 3.1	46.4 ± 3.1	45.3 ± 3.3	43.8 ± 3.7	45.6 ± 4.0
%$\dot{V}O_{2max}$ (ml · kg^{-1} · min^{-1})								
CHO-E	9.3 ± 1.9	74.9 ± 8.0	77.0 ± 7.4	79.8 ± 6.4	78.3 ± 5.9	77.7 ± 6.4	78.0 ± 7.1	77.6 ± 6.9
PLA	8.9 ± 1.2	76.1 ± 9.9	79.2 ± 6.0	78.3 ± 4.9	78.7 ± 6.6	76.9 ± 6.3	74.4 ± 6.8	77.3 ± 7.0
Carbohydrate oxidation rates (kJ · min^{-1})								
CHO-E	3.3 ± 3.4	43.0 ± 10.5	43.0 ± 11.5	42.3 ± 7.8	40.1 ± 7.4	37.7 ± 6.8	39.1 ± 11.2	40.9 ± 8.5*
PLA	3.6 ± 3.4	37.1 ± 12.0	36.8 ± 11.7	34.4 ± 7.7	34.4 ± 6.0	33.8 ± 7.1	29.2 ± 7.6	34.3 ± 7.1
Free fatty acid (FFA) oxidation rates (kJ · min^{-1})								
CHO-E	4.4 ± 3.0	19.8 ± 10.1	21.5 ± 11.1	24.4 ± 8.7	25.4 ± 9.2	27.2 ± 8.0	26.1 ± 10.7	24.1 ± 8.9*
PLA	3.8 ± 3.2	26.5 ± 8.1	29.4 ± 11.1	31.0 ± 8.8	31.3 ± 7.7	30.4 ± 9.3	32.7 ± 9.2	30.2 ± 7.9
Energy expenditure rates (kJ · min^{-1})								
CHO-E	7.7 ± 1.3	62.8 ± 6.6	64.5 ± 6.9	66.7 ± 5.3	65.5 ± 5.4	64.9 ± 6.1	65.3 ± 7.0	65.0 ± 6.2
PLA	7.4 ± 0.9	63.6 ± 7.7	66.2 ± 4.5	65.4 ± 4.2	65.7 ± 4.2	64.2 ± 4.1	61.9 ± 4.0	64.5 ± 5.0

Note: *Main effect of treatment, significantly higher than placebo trial, $P < 0.05$.

The respiratory exchange ratio was significantly higher in the carbohydrate-electrolyte condition throughout exercise (0.89 ± 0.04 vs. 0.86 ± 0.04, carbohydrate-electrolyte vs. placebo; $P = 0.04$) (Figure 4). Mean estimated carbohydrate oxidation rates were significantly higher in the carbohydrate-electrolyte trial (2.4 ± 0.5 g · min^{-1} vs. 2.0 ± 0.4 g · min^{-1}, carbohydrate-electrolyte vs. placebo; $P = 0.01$), whereas mean fat oxidation rates were significantly higher in the placebo trial (0.6 ± 0.2 g · min^{-1} vs. 0.8 ± 0.2 g · min^{-1}, carbohydrate-electrolyte vs. placebo; $P = 0.02$). However, estimated energy expenditure rates were not different between trials (Table II).

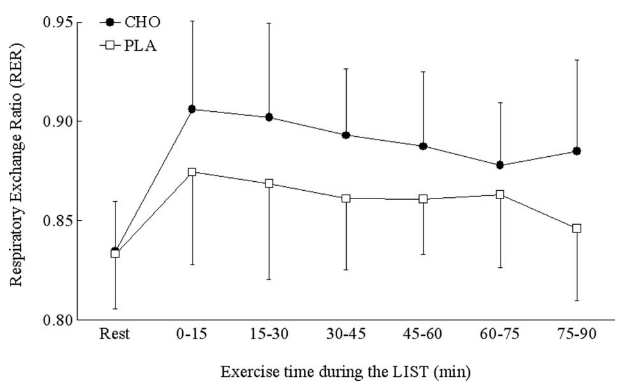

Figure 4. Mean respiratory exchange ratios (RER) during the Loughborough Intermittent Shuttle Test (LIST) in the carbohydrate-electrolyte (CHO-E) and placebo (PLA) trials ($n = 17$).

Blood analyses

There were two main effects as well as an interaction effect of treatment × time for plasma glucose concentration during exercise ($P < 0.001$). Plasma glucose concentrations were maintained above resting values during the carbohydrate-electrolyte trial but there was a marked fall after 30 min of exercise in the placebo trial; significant differences were found at 60 and 90 min [5.4 ± 0.2 mmol · l^{-1} vs. 4.6 ± 0.2 mmol · l^{-1} (60 min) and 5.2 ± 0.1 mmol · l^{-1} vs. 4.0 ± 0.3 mmol · l^{-1} (90 min), carbohydrate-electrolyte *vs.* placebo; $P = 0.02$ and $P = 0.001$, respectively] (Figure 5).

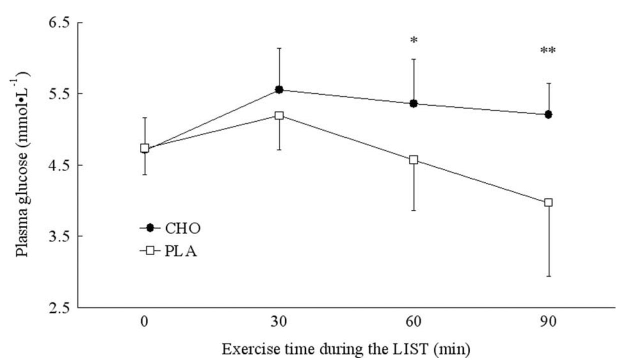

Figure 5. Plasma glucose concentration (mmol · l^{-1}) during the Loughborough Intermittent Shuttle Test (LIST) in the carbohydrate-electrolyte (CHO-E) and placebo (PLA) trials ($n = 10$). *Significantly higher in the carbohydrate-electrolyte trial, $P < 0.05$. **Significantly higher in the carbohydrate-electrolyte trial, $P < 0.01$.

Plasma free fatty acid concentrations showed two main effects as well as an interaction of treatment × time ($P < 0.01$). Mean concentrations were maintained at near resting values in the carbohydrate-electrolyte trial but increased markedly in the placebo trial. Statistically significant differences were observed at 60 and 90 min of exercise [0.5 ± 0.0.3 mmol · l^{-1} vs. 0.9 ± 0.4 mmol · l^{-1} (60 min) and 0.6 ± 0.4 mmol · l^{-1} *vs.* 1.1 ± 0.6 mmol · l^{-1} (90 min), carbohydrate-electrolyte vs. placebo; $P = 0.04$ and $P = 0.01$, respectively] (Figure 6).

Plasma lactate concentrations increased from rest and were higher during exercise (main effect of time, 1.0 ± 0.2 mmol · l^{-1} vs. 3.3–3.6 mmol · l^{-1}, rest vs. exercise; $P < 0.01$) (Table III). Although the concentrations of lactate were consistently higher in the carbohydrate-electrolyte condition, there was no statistical difference between trials.

There was a fall in serum insulin concentration from rest to exercise (main effect of time, 19.2 ± 5.5 mIU · l^{-1} vs. 13–14 mIU · l^{-1}, rest vs. exercise; $P < 0.01$). Insulin concentrations showed a trend to be higher during all exercise sampling times in the carbohydrate-electrolyte trial but this was not statistically significant ($P = 0.07$; Table III). There was

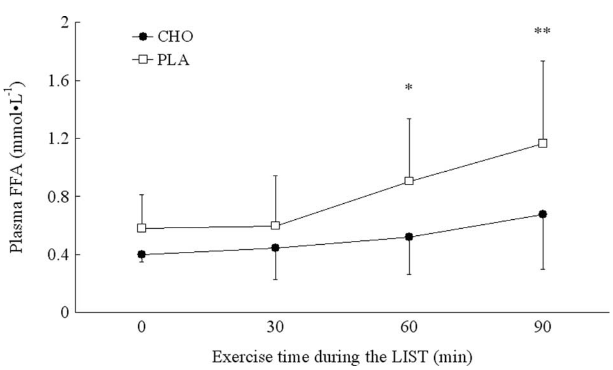

Figure 6. Plasma free fatty acid (FFA) concentration (mmol · l^{-1}) during the Loughborough Intermittent Shuttle Test (LIST) in the carbohydrate-electrolyte (CHO-E) and placebo (PLA) trials ($n = 10$). *Significantly higher in the placebo trial, $P < 0.05$. **Significantly higher in the placebo trial, $P < 0.01$.

Table III. Concentrations of plasma lactate and serum insulin during the Loughborough Intermittent Shuttle Test (LIST) in the carbohydrate-electrolyte (CHO-E) and placebo (PLA) trials (mean ± *s*; $n = 10$).

	Exercise time during the LIST (min)			
	0	30	60	90
Plasma lactate (mmol · l^{-1})				
CHO-E	1.1 ± 0.2*	3.9 ± 1.9	3.5 ± 1.5	3.6 ± 1.3
PLA	1.0 ± 0.2*	3.4 ± 0.9	3.1 ± 1.0	3.2 ± 0.6
Insulin (mIU · l^{-1})				
CHO-E	18.6 ± 5.0*	15.2 ± 3.3	14.5 ± 2.9	13.7 ± 2.6
PLA	19.8 ± 6.2*	13.1 ± 3.4	13.3 ± 2.9	12.3 ± 2.5

Note: *Significantly different from all exercise time points, $P < 0.01$.

only a marginal increase in plasma volume from pre- to post-exercise and no significant difference between trials (+1.0 ± 4.0% vs. +1.8 ± 4.7%, carbohydrate-electrolyte vs. placebo trials; $P = 0.95$).

Perceptual data

There was a main effect of time for ratings of perceived exertion, with the mean value during each block of exercise significantly higher than the previous one ($P < 0.01$; Table IV). Furthermore, we found an interaction effect of treatment × time ($P = 0.03$) but *post-hoc* analyses did not reveal any differences between trials at any sampling times.

Discussion

The aims of this study were to determine whether there was a gradual (i.e. throughout exercise) or rapid (i.e. immediately at the end of exercise) decline in soccer skill performance during exercise, and whether carbohydrate ingestion may offset any such decline. Ignoring any effects of treatment there was a significant time effect ($P = 0.001$), with performance appearing to be maintained throughout most of the exercise and decreasing only during the later stages of the test. Therefore, to simply report pre- and post-exercise changes in skill does not provide the full picture regarding changes in soccer skill performance. We also found that from pre- to post-exercise there was a 3% fall in soccer skill performance in the carbohydrate-electrolyte trial but a concomitant 14% decrease in the placebo trial ($P = 0.07$; Cohen's $d = 0.53$). However, it should be noted that the players were in a glycogen-reduced state before beginning the simulated soccer exercise, which would be unlikely to occur during competitive match-play.

Reilly (1996) suggested the reason why most goals are scored towards the end of a soccer match (last 15 min) are lapses in concentration by defending players. The results of the current study appear to support this statement, as skill performance deteriorated at 75 and 90 min of exercise (Figure 2). A possible explanation for this decrement in skill performance may be levels of arousal. Easterbrook (1959) suggested that there is an inverted-U relationship between arousal and performance. His theory states that when arousal is low (at rest) performance is also low, whereas exercise of moderate intensity increases arousal and this is associated with peak cognitive and motor performance (top of inverted-U); further increases in arousal, for example with fatiguing exercise (e.g. last 15 min of a soccer match), result in a return of performance to baseline values. Although it is possible that this may have occurred in the current study, there is not enough evidence to support this contention. Moreover, a relationship between arousal and concentrations of catecholamines has also been reported (Cooper, 1973) but, as catecholamine concentrations were not measured during this study, this association is only speculative and warrants further investigation.

Zeederberg and colleagues (1996) assessed skill proficiency when tackling opponents as well as in controlling, passing, dribbling, heading, and shooting the ball throughout a game. They did not report any difference in soccer skill during the game irrespective of whether the participants consumed carbohydrate or not. However, the lack of experimental control during this field study reduces the validity of the results. However, using a more controlled laboratory protocol, Northcott et al. (1999) showed that passing and shooting performance improved from the pre-test up to 60 min of exercise and then deteriorated to pre-exercise values. Therefore, these results also suggest an inverted-U performance curve during soccer, but the authors were unable to explain why this occurred. Further investigations into the temporal changes of skill performance during soccer are thus warranted.

In a recent study on soccer skill performance (Ali et al., 2007b), we gave participants 30 g $\cdot$ h^{-1} of carbohydrate during the Loughborough Intermittent Shuttle Test and observed a tendency for soccer passing performance to be better maintained in the carbohydrate-electrolyte trial [1% vs. 6% ($P = 0.13$) decrease from pre- to post-exercise in carbohydrate-electrolyte and placebo trials, respectively). In the present study, the decrements in performance were 3% and 14% in the carbohydrate-electrolyte and placebo trials, from pre- to post-exercise, respectively ($P = 0.07$). Therefore, there does not seem to be any added benefits of increasing the carbohydrate delivery rate from 30 to 52 g $\cdot$ h^{-1} when attempting to maintain soccer skill performance. Furthermore, even though sprint performance appeared to be better maintained in the last 30 min of the Loughborough Intermittent Shuttle Test in the carbohydrate-electrolyte trial, there was no statistically significant difference between trials as a consequence of the increased delivery of carbohydrate (Figure 3).

In the carbohydrate-electrolyte trial, significantly higher respiratory exchange ratio values were observed throughout exercise ($P = 0.04$; Figure 4), which is indicative of higher rates of carbohydrate oxidation ($P = 0.01$; Table II). In contrast, we observed higher rates of fat oxidation in the placebo than the carbohydrate-electrolyte trial ($P = 0.02$; Table II) but no differences in overall energy expenditure between trials. Plasma glucose concentrations were maintained above resting values throughout exercise but fell below 4 mmol $\cdot$ l^{-1} after exercise in the placebo trial ($P < 0.01$; Figure 5). Serum insulin concentrations tended to be higher

Table IV. Ratings of perceived exertion during the Loughborough Intermittent Shuttle Test (LIST) in the carbohydrate-electrolyte (CHO-E) and placebo (PLA) trials (mean $\pm$ *s*; $n = 17$).

	Exercise time during the LIST (min)					
	0–15	15–30	30–45	45–60	60–75	75–90
CHO-E	11.6 ± 1.1	12.7 ± 1.0	13.6 ± 1.3	14.6 ± 1.8	14.9 ± 1.9	15.2 ± 2.1
PLA	11.6 ± 1.4	12.6 ± 1.6	13.4 ± 1.4	14.1 ± 1.7	15.4 ± 2.1	16.1 ± 2.7

Table V. Comparison of metabolic variables between the study of Ali et al. (2007b) and the current study: Mean ($\pm$ *s*) values for the carbohydrate-electrolyte (CHO-E) and placebo (PLA) trials for each study are shown.

	Carbohydrate delivery rate			
	30 g · h^{-1} (Ali et al., 2007b)		52 g · h^{-1} (current study)	
	CHO-E	PLA	CHO-E	PLA
Respiratory exchange ratio	0.90 ± 0.04	0.90 ± 0.03	0.89 ± 0.04*	0.86 ± 0.04
Estimated energy expenditure (kJ · min^{-1})	67.7 ± 8.2	65.4 ± 7.9	65.0 ± 6.2	64.5 ± 5.0
Estimated carbohydrate oxidation (kJ · min^{-1})	44.8 ± 11.8*	42.7 ± 1.1	40.9 ± 8.5*	34.3 ± 7.1
Estimated fat oxidation (kJ · min^{-1})	22.9 ± 8.4	22.7 ± 8.7	24.1 ± 8.9*	30.2 ± 7.9
Plasma glucose (mmol · l^{-1})	5.2 ± 0.7*	4.6 ± 0.9	5.2 ± 0.6*	4.6 ± 0.8
Plasma FFA (mmol · l^{-1})	0.7 ± 0.4*	0.8 ± 0.4	0.5 ± 0.3*	0.8 ± 0.4
Insulin (mIU · l^{-1})	14.8 ± 1.7	13.9 ± 2.0	14.5 ± 2.9	12.9 ± 2.9

*Significantly different from corresponding placebo trial, $P < 0.05$.

with carbohydrate ingestion ($P = 0.07$; Table III), whereas plasma free fatty acid concentrations were higher in the placebo trial throughout exercise ($P < 0.01$; Figure 6). These values are similar to those reported in our previous study in which the soccer players ingested the equivalent of only $30\ g \cdot h^{-1}$ of carbohydrate (Ali et al., 2007b). Table V provides a comparison of metabolic data between the current study and that of Ali et al. (2007b). Regardless of the carbohydrate delivery rate between studies, there were similar responses between carbohydrate and placebo trials. Therefore, increasing the carbohydrate delivery rate to $52\ g \cdot h^{-1}$ does not appear to have significantly changed metabolic responses when performing the 90-min soccer simulation exercise. Regarding dose–response issues, Carter and colleagues (Carter, Jeukendrup, & Jones, 2004) recently showed that simply rinsing the mouth with carbohydrate has some effect on performance; whether the same applies to soccer performance requires further research.

Coyle and Montain (1992) proposed that an exogenous carbohydrate delivery rate of 30–$60\ g \cdot h^{-1}$ is sufficient to delay fatigue during prolonged exercise by maintaining blood glucose concentrations and carbohydrate oxidation. In the present study, the participants began exercise probably with low glycogen stores and so it is surprising that a greater metabolic response was not observed. However, it may be that a delivery rate of $30\ g \cdot h^{-1}$, as provided in our previous study, is sufficient to maintain higher plasma glucose concentrations and increased carbohydrate oxidation rates. As mentioned earlier, the respiratory exchange ratio values suggest a significantly higher contribution of carbohydrate oxidation in the carbohydrate-electrolyte trial, with the overall rates during the carbohydrate-electrolyte and placebo trials of 2.4 and 2.0 $g \cdot min^{-1}$, respectively. This was similar to the overall carbohydrate oxidation rates in a previous study ($2.5\ g \cdot min^{-1}$; Ali et al., 2007b) and so there may be a threshold for carbohydrate oxidation during this type of exercise. Nevertheless, whether there was a difference in the oxidation of the exogenous carbohydrate due to the different supply rates ($30\ g \cdot h^{-1}$ vs. $52\ g \cdot h^{-1}$) cannot be determined without the use of tracer technology.

In summary, soccer skill performance appears to decline during the last 15 min of exercise within the 90-min intermittent running test. This finding is in line with research that shows most goals are scored during this period. The reason for this could relate to changes in arousal, which lead to lapses in concentration or ball control in players towards the end of the game. Moreover, the common practice of simply monitoring skill performance before and after a period of exercise may be inappropriate. Supplying carbohydrate at a rate of $52\ g \cdot h^{-1}$ during exercise does not provide any further benefits in terms of maintaining skill and sprint performance relative to a lower ($30\ g \cdot h^{-1}$) dose. Nevertheless, it is important to note that the provision of carbohydrate (whether 30 or to $52\ g \cdot h^{-1}$) appears to induce metabolic and perceptual benefits relative to when no carbohydrate is provided to players.

Acknowledgements

The authors wish to thank GlaxoSmithKline for funding this project and members of the university association football team for volunteering to participate in the study.

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