The Influence of Carbohydrate–Electrolyte Ingestion on Soccer Skill Performance

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ABSTRACT

ALI, A., C. WILLIAMS, C. W. NICHOLAS, and A. FOSKETT. The Influence of Carbohydrate–Electrolyte Ingestion on Soccer Skill Performance. *Med. Sci. Sports Exerc.*, Vol. 39, No. 11, pp. 1969–1976, 2007. **Purpose:** To investigate the effect of ingesting a carbohydrate–electrolyte solution (CHO-E), in subjects with reduced carbohydrate stores, during an intermittent shuttle running test (LIST) on soccer passing (LSPT) and shooting (LSST) performance. **Methods:** Sixteen healthy male university soccer players ingested either a 6.4% CHO-E or placebo (PLA) solution during 90 min of the LIST (5 mL·kg^{-1} BM before and 2 mL·kg^{-1} BM every 15 min of exercise), in a double-blind, randomized, crossover design, with each trial separated by at least 7 d. On the evening before the main trial (17:00 h), subjects performed the glycogen-reducing cycling exercise (~80 min at 70% $\dot{V}O_{2max}$). They were then fed a low-carbohydrate evening meal and reported to the laboratory the following morning after a 10-h fast. Blood was collected at rest and after every 30 min of exercise; skill tests were performed before and after the LIST. **Results:** The change in mean LSST performance from pre- to post-LIST was better in the CHO-E trial (11 ± 45 vs −16 ± 42%; $P < 0.01$) but not significantly different for the LSPT performance (−1 ± 10% (CHO-E) vs −6 ± 13% (PLA), $P = 0.13$). Sprint performance during the LIST was quicker in the CHO-E trial (2.50 ± 0.13 vs 2.53 ± 0.13 s, $P < 0.01$). Plasma glucose was higher in the CHO-E trial after 90 min of exercise (5.2 ± 0.3 vs 3.9 ± 0.4 mM, $P < 0.01$). **Conclusions:** Ingestion of a carbohydrate–electrolyte solution during exercise enabled subjects with compromised glycogen stores to better maintain skill and sprint performance than when ingesting fluid alone. **Key Words:** LOW MUSCLE GLYCOGEN, FLUID INGESTION, SPRINT PERFORMANCE, FATIGUE, GLUCOSE

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Match analysis shows that soccer players work at a rate that is equivalent to 70–80% $\dot{V}O_{2max}$ (3) and that prolonged exercise at these intensities places a heavy reliance on glycogen as a substrate for energy metabolism (23,24). There is a well-documented association between glycogen depletion and fatigue during prolonged, heavy exercise (4,24). For example, Saltin (24) has shown that low muscle glycogen concentrations were associated with a lower work rate in a soccer match. Those players who began the match with low muscle glycogen concentrations covered less ground and completed less time in high-intensity running than the players who had normal glycogen concentrations. However, no mention was made of the decrements in skill levels with the onset of fatigue during the match (24).

Fluid ingestion during prolonged exercise helps delay the onset of fatigue and reduces the rate of use of muscle glycogen (10,12). Soccer players are recommended to drink before and, when the opportunities present themselves, during matches to avoid dehydration-induced fatigue (15). Furthermore, drinking a carbohydrate solution during a match may not only help to delay the onset of severe dehydration, it also may improve work rate (14). The capacity to continue to perform high-intensity shuttle running is improved when a carbohydrate–electrolyte solution rather than a placebo is ingested (8,19,27). Although the ingestion of carbohydrate–electrolyte solutions do not seem to improve either peak power output on treadmill testing (6) or the number of shuttle sprints performed before the onset of fatigue (17), this type of exercise is not directly relevant to the type of free running common in soccer. Welsh and colleagues (27) explored the benefits of ingesting a carbohydrate–electrolyte solution during prolonged intermittent high-intensity shuttle running on motor and cognitive performance. They found that there were benefits in gross motor skill but not in cognitive performance (27). There are some field studies on the influence of carbohydrate ingestion on soccer skill performance, but they are limited by the multitude of extraneous factors that impinge on skill performance in soccer matches (28). In one controlled study of soccer-specific skill, McGregor and colleagues (16) examined the influence of fluid intake on ball dribbling before and after prolonged intermittent high-intensity shuttle running. They found that

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the ball-dribbling skill of soccer players decreased by 5% when they conducted the test without ingesting water (16). However, there seems to be little information on soccer-specific skills such as passing and goal shooting, because of the lack of validated skill tests.

One of the interesting questions in the study of skill performance of soccer players is whether soccer skills can be sustained by the ingestion of carbohydrate—that is, the contribution to endogenous carbohydrate stores. Therefore, the aim of this study was to investigate whether ingestion of a carbohydrate–electrolyte solution before and during prolonged intermittent high-intensity shuttle running would have any beneficial effects on skill performance by soccer players with reduced carbohydrate stores. The purpose of reducing the players' endogenous carbohydrate stores before the tests was to help identify more clearly the possible impact of the exogenous carbohydrate–electrolyte solution on skill performance.

METHODS

Subjects. Sixteen healthy male soccer players (mean ± SD: age 21.3 ± 3.0 yr, height 1.8 ± 0.07 m, body mass (BM) 74.6 ± 6.8 kg, and $\dot{V}O_{2max}$ 56.0 ± 1.6 $mL \cdot kg^{-1} \cdot min^{-1}$) volunteered to participate in the study. The players were semiprofessional, ex-professional, or players of at least university first/second team standard. They were from a range of outfield playing positions and were involved in regular training and match play. All procedures had prior approval by Loughborough University's ethical advisory committee. After completion of a health screening questionnaire, written informed consent was obtained from all subjects.

Preliminary measurements. Subjects reported to the laboratory on two separate occasions for preliminary measurements. During the first session, along with physiological measurements (height and mass), maximal oxygen uptake ($\dot{V}O_{2max}$) was estimated by means of the *progressive multistage fitness shuttle run test* (22). Subjects were also fully familiarized with the skill tests and the prolonged intermittent high-intensity shuttle running protocol (LIST) during both sessions (21).

Experimental procedures. Subjects completed two main trials, each separated by at least 7 d. The order of trials was randomized to counteract order effects. Subjects were asked to record their food and drink consumption for the 2 d before the main trials, and to replicate their intake before both trials. During this time mean energy (11.2 ± 0.6 vs 12.0 ± 0.7 $MJ \cdot d^{-1}$) and carbohydrate intake (393 ± 31 vs 415 ± 31 $g \cdot d^{-1}$) were similar between trials. Each main trial took place during 2 d (Fig. 1). On the first day, the subjects reported to the laboratory at approximately 17:00 h. After a standardized 10-min warm-up, they performed the preexercise skill tests (Loughborough Soccer Passing Test (LSPT) (2) and Loughborough Soccer Shooting Test (LSST) (2)), which were used to set the "baseline" performance values. In the LSST, the shot speed was monitored using a radar system that is commercially available for use in sport (The SpeedChek sports radar: Tribar Industries Inc., Coachwise 1st4sport, Leeds). After a brief rest period (5–10 min), they undertook a period of prolonged cycling to reduce their muscle glycogen stores using a procedure originally designed for this purpose by Vollestad et al. (26) and confirmed by Bowtell and colleagues (5). Briefly, this procedure required the subjects 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 of rest between each bout), and then another 45 min at 70% $\dot{V}O_{2max}$. After completing this exercise, the subjects were provided with a low-carbohydrate meal at approximately

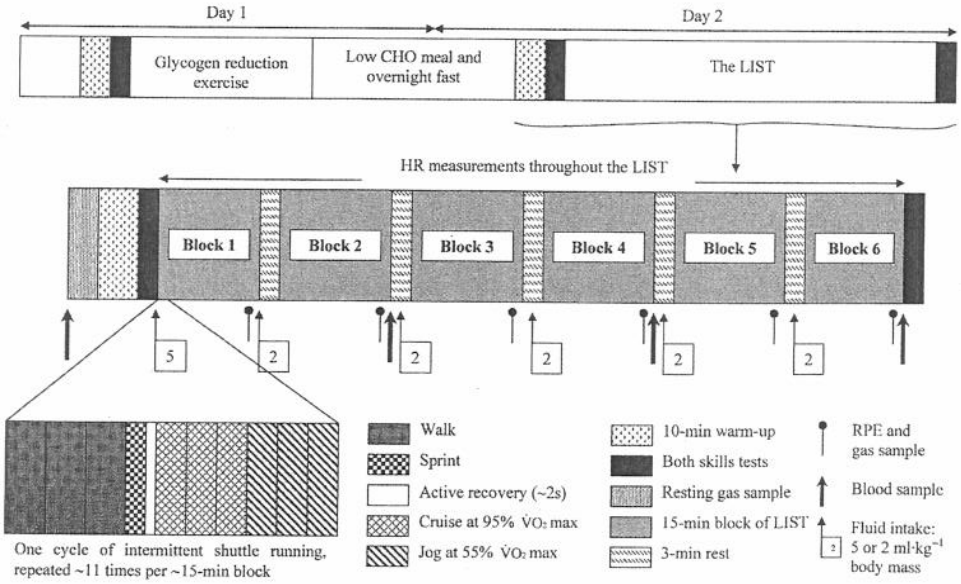

FIGURE 1—Schematic representation of the experimental protocol and the Loughborough Intermittent Shuttle Test (LIST).

20:00 h, which was the last meal of the day (energy content of 56 $kJ \cdot kg^{-1}$ BM and carbohydrate content of 1 $g \cdot kg^{-1}$ BM). Thereafter, they were instructed not to consume any other food after this meal, but they were allowed to consume water *ad libitum*. After this procedure, the subjects arrived in the laboratory the following morning, having fasted for approximately 12 h.

On arrival on the morning of day 2, the subjects' nude body mass was determined, and then a cannula (Venflon 18G, Sweden) was inserted into a forearm vein while the subject lay on an examination couch. The cannula was kept patent with frequent flushing with sterile saline. After the cannulation procedure was completed, subjects stood for 10 min before resting blood and expired air samples were collected. After the same standardized warm-up procedure, subjects performed the second set of skill tests (pre-LIST) and then drank one of the test solutions. In the carbohydrate trial, subjects were provided with a commercially available sports drink containing 6.4% carbohydrate (Lucozade Sport). In the other trial, they drank a nonelectrolyte, artificially sweetened placebo that contained no carbohydrate (PLA). The artificial sweeteners, present in both the CHO and PLA drinks, were aspartame and acesulfame K. Both solutions looked, tasted, and had the same mouth feel and were manufactured by the same company (GlaxoSmithKline, Brentford). Subjects were asked after the trial to try to identify which of the solutions they had consumed in the two trials. Their responses showed quite clearly that they did not know the order of treatments. Before the commencement of the LIST, subjects ingested a volume equivalent to 5 $mL \cdot kg^{-1}$ BM and then 2 $mL \cdot kg^{-1}$ BM after every 15 min of exercise.

After ingestion of the test drink, participants completed six 15-min blocks of the LIST, punctuated by 3-min rest periods. Each 15-min block consists of 10–12 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 (see Nicholas et al. (21) for more specific details). Within the rest periods, subjects ingested the equivalent of 2 $mL \cdot kg^{-1}$ BM of the same drink. Expired air was collecting using the modified Douglas bag method—that is, a Douglas bag (and associated apparatus) attached to a rucksack worn by the subject during the last two complete cycles of the LIST per 15-min block of exercise. The first cycle allowed further familiarization of the device, and also to clear atmospheric air from the dead space in the tubing; expired air was collected during the second full cycle. Measurement of fractional concentration of CO_2 and O_2 was performed using the Servomex (model 1440C) gas-analysis apparatus, and a Harvard dry-gas digital meter was used to measure volume of expired air. Ratings of perceived exertion (RPE) and environmental temperature were measured on the last walk phase of each 15-min block of exercise. Heart rate (HR) was monitored continuously throughout exercise via short-range telemetry (Vantage NV, Polar, Finland). The subjects were constantly encouraged to maintain the pace set by the audio signals and to perform maximally during the sprints. After completion of the LIST, they were given a brief (2 min) rest before the postexercise skill tests. Nude body mass was determined after the post-LIST skill tests, after subjects had towel dried themselves to remove excess sweat.

Blood analyses. Blood samples were withdrawn from an indwelling venous cannula, in volumes of 10 mL, at rest and after 30, 60, and 90 min of the LIST. All blood-collection procedures were performed as described in previous studies from this laboratory (16). Changes in plasma volume were determined via hematocrit and hemoglobin concentrations (9); plasma samples were analyzed for glucose, lactate, and FFA concentration, and serum samples for insulin, using methods described previously (16,19).

Statistical analyses. The data were examined using a two-factor (drink treatment × time of measurement) analysis of variance (ANOVA), with repeated measures for correlated data (SPSS version 10). Mauchly's test of sphericity was used to determine whether the assumption of sphericity was being violated by the data. Where this did occur, the Huynh–Feldt correction was applied (SPSS). When differences were found by the ANOVA, paired Student's *t*-tests using the Bonferroni adjustment were used to ascertain where the differences lay. Paired Student's *t*-tests were also used to examine delta change values in skill performance between trials. Data are presented as means ± SD. The level of significance was accepted at $P < 0.05$.

RESULTS

Two-way ANOVA and/or paired Student's *t*-tests were performed on all trial 1 versus trial 2 data, and there were no significant differences between trials; thus, any differences between conditions are likely attributable to treatment effects. All subjects ($N = 16$) were able to complete the prolonged cycling bout, the 90-min LIST, and skill tests for both CHO-E and PLA trials. However, blood samples were obtained from only 10 subjects, because two subjects had an adverse reaction to the cannulation procedure, and so we did not include their results; the remainder ($N = 4$) did not wish to provide blood samples, but they were willing to perform the rest of the testing procedures. All data relating to blood variables will indicate $N = 10$ throughout the remainder of the manuscript (note that the power analyses were based on $N = 16$ for performance data and does not apply to blood measures).

LSPT. Although LSPT performance time seemed to be better maintained from pre-LIST to post-LIST in the CHO-E trial, this was not statistically significant (CHO-E trial: 50.5 ± 5.5 to 50.8 ± 4.8 s; PLA trial: 51.2 ± 5.4 to 54.0 ± 5.3 s; $P = 0.13$; Fig. 2). The LSPT total performance time consists of time taken to complete the test plus any

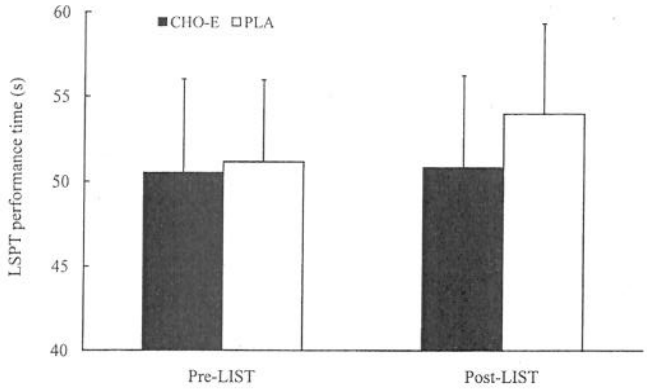

FIGURE 2—Mean LSPT performance times from pre-LIST to post-LIST for CHO-E and PLA trials ($N = 16$).

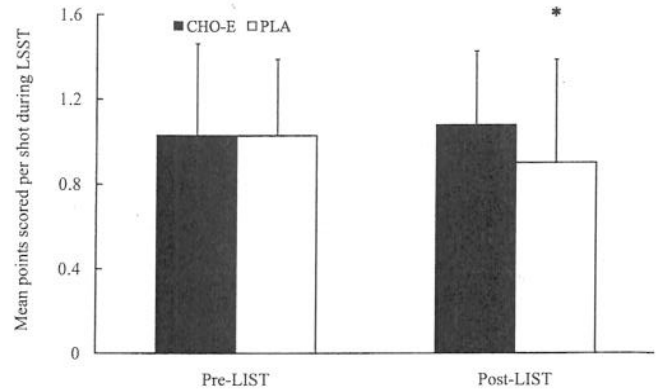

FIGURE 3—Mean LSST points scored per shot from pre-LIST to post-LIST for CHO-E and PLA trials. * Significantly different from pre-LIST ($P < 0.01$, $N = 16$).

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additional penalty time for inaccurate passes and poor ball control. The time taken to complete the LSPT was the same between trials (Table 1). There was a tendency for penalty time to increase to a greater extent from baseline to post-LIST in the PLA trial (7.5 ± 3.2 vs 11.5 ± 4.4 s) than in the CHO-E trial (8.4 ± 3.2 vs 9.5 ± 4.1 s; Table 1), but this was not statistically significant.

LSST. There was a significant difference in mean points scored per shot from pre-LIST to post-LIST between treatments (CHO-E trial: +0.06 ± 0.5 points; PLA trial: −0.13 ± 0.4 points; $P < 0.01$; Fig. 3). There were no differences between trials in mean time taken to complete each shot sequence or mean shot speed (Table 2).

Mean 15-m sprint performance. Mean sprint time during the 90 min of the LIST was faster in the CHO-E trial (2.50 ± 0.13 vs 2.53 ± 0.13 s, CHO-E vs PLA, $P < 0.05$; Fig. 4). There was also a main effect of time, with the combined (CHO-E + PLA) times during blocks 5 (2.56 ± 0.13 s) and 6 (2.57 ± 0.12 s) significantly slower than blocks 1 (2.49 ± 0.12 s) and 2 (2.48 ± 0.13 s; $P < 0.01$).

HR and RPE. Although there was a trend towards higher HR values during the CHO-E trial, this was not statistically significant. There was a main effect of time, with mean HR significantly lower during the first 15 min of exercise than for blocks 2–6 (158 ± 9 vs 163–165 bpm, block 1 vs blocks 2–6, $P < 0.01$).

There was a main effect of time for RPE during the LIST, reflecting that the subjects found the exercise harder during both trials as the trial progressed ($P < 0.01$). There was also an interaction effect of treatment by time, with a significant difference between trials in block 6 only (17.4 ± 1.5 vs 16.6 ± 1.9, PLA vs CHO-E, $P < 0.01$).

Oxygen uptake, exercise intensity, and RER. Oxygen uptake was consistently higher during the CHO-E trial, with the overall value significantly greater than the PLA trial (45.9 ± 2.7 vs 44.2 ± 2.9 $mL \cdot kg^{-1} \cdot min^{-1}$, CHO-E vs PLA, $P < 0.01$; Table 3). Oxygen uptake was also higher in the first 30 min of the LIST than in the last two blocks of exercise (45.8 ± 2.8 vs 44.3 ± 2.6 $mL \cdot kg^{-1} \cdot min^{-1}$, blocks 1 and 2 vs blocks 5 and 6, $P < 0.01$). This also equated to a consistently higher relative exercise intensity, expressed as a percentage of maximal oxygen uptake ($\%\dot{V}O_{2max}$), in the CHO-E trial (82.0 ± 4.8 vs 79.3 ± 4.7%, CHO-E vs PLA, $P < 0.01$; Table 3). Percent $\dot{V}O_{2max}$ was also higher in blocks 1 and 2 than in blocks 5 and 6 (82.0 ± 4.9 vs 79.4 ± 4.6%, blocks 1 and 2 vs blocks 5 and 6, $P < 0.01$). Although subjects were exercising at a higher relative intensity, there was no difference in RER (Table 3). However, the average rate of CHO oxidation for the CHO-E trial as a whole was significantly higher ($P < 0.01$) than the value for the PLA trial (Table 3).

Plasma glucose and FFA. There were two main effects as well as an interaction effect for plasma glucose results. Plasma glucose concentrations were maintained in the CHO-E trial, but they decreased with duration of exercise in the PLA trial. There was a significant difference between trials at 30 and 90 min (5.6 ± 0.4 vs 5.1 ± 0.5 mM (30 min) and 5.2 ± 0.8 vs 3.9 ± 1.1 mM (90 min), CHO-E vs PLA, $P < 0.05$; Fig. 5). Conversely, plasma FFA concentrations were consistently higher during exercise in

TABLE 1. Mean ± SD time taken to complete (s), and penalty time accrued (s), during the LSPT in the CHO-E and PLA trials ($N = 16$).

	Pre-LIST	Post-LIST	Change (%)
Time only (s)			
CHO-E	42.0 ± 3.7	41.3 ± 3.3	−1.3
PLA	42.0 ± 3.7	42.5 ± 4.2	1.2
Penalty time only (s)			
CHO-E	8.5 ± 3.6	9.5 ± 4.1	24.4
PLA	9.1 ± 3.4	11.5 ± 4.4	41.9

TABLE 2. Mean ± SD time taken to complete each shot sequence (s) and speed of each shot ($km \cdot h^{-1}$) during the LSST in the CHO-E and PLA trials ($N = 16$).

	Pre-LIST	Post-LIST	Change (%)
Time taken per shot sequence (s)			
CHO-E	8.42 ± 0.21	8.56 ± 0.21	1.7
PLA	8.57 ± 0.15	8.63 ± 0.19	0.6
Mean shot speed ($km \cdot h^{-1}$)			
CHO-E	74.5 ± 6.4	74.5 ± 4.2	0.4
PLA	72.4 ± 5.1	72.3 ± 6.0	0.2

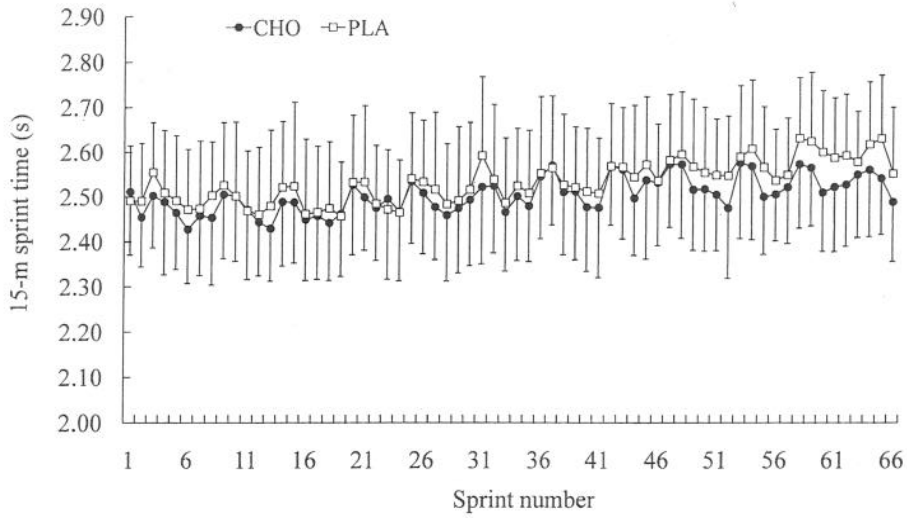

FIGURE 4—Mean 15-m sprint time (s) during the LIST in CHO-E and PLA trials (N = 16).

the PLA trial (Fig. 6). There was an interaction effect of time by treatment ($P < 0.05$), but the *post hoc* analysis did not show any significant differences between trials at any single sampling time. There was also a time effect, with plasma FFA decreasing from rest to 30 min, but then rising until the end of exercise ($P < 0.01$).

Plasma lactate and serum insulin. Plasma lactate concentrations were significantly higher during exercise than at rest ($P < 0.01$; Table 4) but were not different between trials. Similarly, although serum insulin concentration was consistently higher during exercise in the CHO-E trial, this was not significantly different from the PLA trial (Table 4).

Plasma volume and body mass. There was no significant difference between trials in the changes in plasma volume from rest to the end of exercise (−3.3 ± 1.2 and −4.1 ± 1.7%, CHO-E and PLA trials, respectively). Absolute (1.4 ± 0.5 vs 1.3 ± 0.3 kg, CHO-E vs PLA) and relative (1.8 ± 0.6 vs 1.8 ± 0.4%, CHO-E vs PLA) body mass loss was the same during both trials.

DISCUSSION

One of the main findings of this study was that soccer shooting performance was maintained in the CHO-E trial but deteriorated after exercise in the PLA trial. Although soccer passing performance showed a tendency to be better maintained in the CHO-E trial after exercise, this was not statistically significant. Furthermore, with carbohydrate–electrolyte ingestion during exercise, players were able to sprint faster throughout the duration of the LIST. However, it must be noted that players in both trials began the LIST with reduced carbohydrate stores.

In the CHO-E trial, the points scored during the LSST increased by a mean of 11%, whereas in the PLA trial, there was a 15% decrease in performance (Fig. 3, $P > 0.01$). It

TABLE 3. Oxygen uptake ($\dot{V}O_2$), relative exercise intensity (%$\dot{V}O_{2max}$), respiratory exchange ratio (RER), oxidation rates of carbohydrate, fat, and energy expenditure rates (kJ·min^{-1}) at rest, during each 15-min block, and overall mean of the LIST in the CHO-E and PLA trials.

		LIST Block Number						
	Rest	1	2	3	4	5	6	Mean of Trial
$\dot{V}O_2$ (mL·kg^{-1}·min^{-1})								
CHO-E	6.3 ± 1.2	46.7 ± 2.7	46.3 ± 2.1	45.6 ± 2.3	45.9 ± 2.9	45.5 ± 2.7	45.3 ± 2.4	45.9 ± 2.7*
PLA	5.9 ± 1.1	44.9 ± 2.6	45.1 ± 2.8	44.8 ± 2.8	43.7 ± 3.5	43.2 ± 2.0	43.1 ± 2.0	44.2 ± 2.9
% $\dot{V}O_{2max}$								
CHO-E	6.2 ± 0.7	83.2 ± 5.1	82.7 ± 4.3	81.6 ± 4.2	81.8 ± 4.9	81.4 ± 4.8	81.0 ± 4.2	82.0 ± 4.8*
PLA	6.2 ± 0.7	80.7 ± 4.5	80.9 ± 5.1	80.4 ± 4.6	79.2 ± 4.0	77.5 ± 3.6	77.3 ± 3.4	79.3 ± 4.7
Respiratory exchange ratio								
CHO-E	0.87 ± 0.08	0.92 ± 0.04	0.92 ± 0.04	0.91 ± 0.03	0.89 ± 0.03	0.89 ± 0.03	0.88 ± 0.03	0.90 ± 0.04
PLA	0.86 ± 0.05	0.92 ± 0.03	0.91 ± 0.02	0.90 ± 0.03	0.89 ± 0.02	0.88 ± 0.02	0.89 ± 0.02	0.90 ± 0.03
Carbohydrate oxidation rates (kJ·min^{-1})								
CHO-E	10.1 ± 2.1	48.3 ± 12.3	49.2 ± 12.9	46.3 ± 10.8	43.1 ± 9.9	41.9 ± 10.2	39.8 ± 10.1	44.8 ± 11.3*
PLA	9.8 ± 2.4	48.4 ± 9.6	45.7 ± 10.5	42.3 ± 11.4	42.9 ± 8.2	38.2 ± 7.7	38.9 ± 7.6	42.7 ± 9.7
Free fatty acid (FFA) oxidation rates (kJ·min^{-1})								
CHO-E	10.1 ± 2.1	20.7 ± 7.9	19.3 ± 9.0	21.1 ± 7.2	24.7 ± 6.0	25.1 ± 6.7	26.8 ± 7.6	22.9 ± 7.8
PLA	9.8 ± 2.4	18.4 ± 5.0	21.3 ± 8.0	24.0 ± 9.2	21.9 ± 8.2	25.7 ± 4.9	24.9 ± 5.1	22.7 ± 7.2
Energy expenditure rates (kJ·min^{-1})								
CHO-E	10.1 ± 0.5	69.0 ± 2.1	68.5 ± 2.1	67.5 ± 2.1	67.7 ± 2.1	67.0 ± 2.1	66.6 ± 1.9	67.7 ± 0.9*
PLA	9.8 ± 0.6	66.8 ± 2.1	66.9 ± 2.0	66.3 ± 2.0	64.8 ± 2.1	63.9 ± 1.8	63.8 ± 1.8	65.4 ± 0.8

* Main effect of treatment, significantly higher than PLA trial ($P < 0.01$, N = 16).

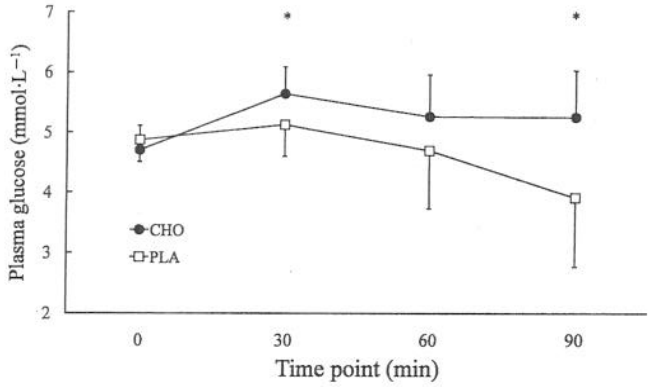

FIGURE 5—Plasma glucose concentration (mM) during the LIST for CHO-E and PLA trials. * Significantly higher in CHO-E trial, $P < 0.05$, $N = 10$.

must be noted that where subjects registered a scoring shot but were unable to shoot the ball above a certain velocity, or did not complete each shot sequence within a certain time limit, this was not added to their performance score. If all scoring shots, regardless of time taken or shot velocity, were taken into account, the mean points scored in the PLA trial post-LIST would have been 1.23 points rather than the actual 0.90 points per shot (Fig. 3). Thus, it would seem that subjects in the PLA condition sacrificed speed of movement and/or reduced shot velocity, to maintain accuracy—the so-called *speed–accuracy trade-off* (11). This suggests that the gross motor aspects of sprinting and force development (for shooting the ball) were compromised after exercise in the PLA trial.

In the CHO-E trial, the change in LSPT performance from pre- to post-LIST was 1.3%, whereas in the PLA trial there was a 6.4% change in performance (Fig. 2, $P = 0.13$). The LSPT consists of time taken to complete each sequence of passes, plus additional time penalty points imposed for inaccurate passes or poor ball control. Because there were no differences between trials for the time-taken element of the test, the decrement in the overall performance can be suggested to be attributable to the additional penalty time

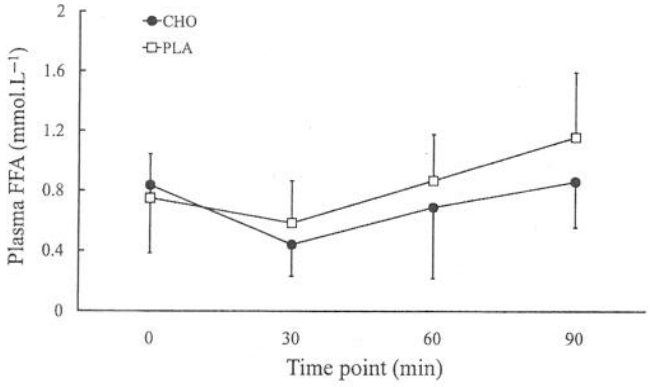

FIGURE 6—Plasma FFA concentration (mM) during the LIST for CHO-E and PLA trials ($N = 10$).

TABLE 4. Concentration of plasma lactate (mM) and serum insulin (mIU·L^{-1}) during the LIST in the CHO-E and PLA trials.

	Exercise Time (min)			
	0	30	60	90
Plasma lactate (mM)				
CHO-E	1.0 ± 0.2*	4.4 ± 1.5	4.1 ± 1.6	4.1 ± 1.2
PLA	1.0 ± 0.2*	4.0 ± 1.2	3.9 ± 1.6	4.2 ± 1.2
Serum insulin (mIU·L^{-1})				
CHO-E	8.6 ± 2.8*	5.7 ± 2.5	4.6 ± 0.9	4.1 ± 0.8
PLA	9.0 ± 4.1*	4.7 ± 1.8	3.8 ± 2.2	3.1 ± 1.7

* Significantly different from all exercise time points ($P < 0.01$, $N = 10$).

(Table 1). Relative to before exercise, post-LIST penalty time was 24 and 42% higher in the CHO-E and PLA trials, respectively (Table 1). This suggests that it was not necessarily gross motor performance (i.e., moving around the grid as quickly as possible) that was affected but either a decrease in finer motor control (e.g., passing and control of ball) and/or cognitive functioning (e.g., decision making and perceptual awareness). Therefore, even though there were no statistical differences between trials, it seems there is a trend for better passing performance with CHO-E ingestion rather than consuming fluid alone during the LIST.

Because of the relative lack of published information on carbohydrate ingestion and skill performance during intermittent sports, it is difficult to make an extensive comparison between the findings of the present study with other studies. For example, Abt and associates (1) found that a 3-d high-carbohydrate diet, when compared with a mixed diet, had no effect on ball-dribbling skill and shooting performance. Their protocol consisted of only 60 min of intermittent exercise, with limited maximal sprinting, and performance of closed soccer skills. Thus, the validity of the study as a means of firstly simulating the demands of soccer and, secondly, determining soccer skill, is questionable. Zeederberg et al. (28) report no effect of a carbohydrate solution consumed before and during a 90-min match on motor skill proficiency of soccer players. They suggest that a possible reason could be the lack of evidence of hypoglycemia in the placebo trial, because, in both trials, blood glucose concentrations were > 5 mM. However, carbohydrate was ingested by the players at a rate of only about 25 g·h^{-1}, a rate that may not have been sufficient to highlight any differences between treatments. Furthermore, the very subjective notion of "skill" (only based on successful/unsuccessful outcomes) within an exhibition or friendly match may have weakened the findings. Clarke et al. (6) did not find any difference in peak power output during treadmill sprinting between placebo and carbohydrate trials. Each sprint lasted about 3 s, and their subjects completed 18 sprints in total, interspersed with running at a lower intensity (67% $\dot{V}O_{2max}$). Maximal sprinting for such short durations rely heavily on the stores of phosphocreatine, which is rapidly resynthesized between sprints (18). Therefore, it is questionable whether the relatively small number of maximal treadmill sprints was sufficient

to severely challenge muscle glycogen stores in their subjects. In contrast, the subjects in the present study complete approximately 66 sprints during each trial, and their overall exercise intensity was close to 80% $\dot{V}O_{2max}$. This exercise intensity, and the number of sprints performed during the LIST, is more applicable to actual soccer matches (3).

Low muscle glycogen may lead to early fatigue and a subsequent decrease in skill level. Jacobs (13) suggests that muscle glycogen concentrations must fall below a critical threshold of 175 $mmol \cdot kg^{-1}$ d.w. for anaerobic performance to be seriously affected. Thus, the anaerobic component of the skill tests may have been hindered by the limited availability of carbohydrate. Nicholas et al. (20) report post-LIST muscle glycogen concentrations of 160 ± 15 $mmol \cdot kg^{-1}$ d.w. and 170 ± 24 $mmol \cdot kg^{-1}$ d.w. after placebo and carbohydrate ingestion, respectively. Although no muscle biopsies were performed after the glycogen-reducing exercise in the present study, the results from a previous study within our laboratory show that this protocol reduced the glycogen concentrations of the quadriceps muscles to very low values, that is, 55 $mmol \cdot kg^{-1}$ d.w. (5). Thus, the addition of the glycogen-reducing exercise, plus the effects of the LIST itself, would have lowered muscle glycogen concentration even further, possibly compromising the ability of the subjects to perform skillfully. Of course, in the absence of muscle glycogen data, we cannot be certain about this speculation. Nevertheless, in terms of real-world scenarios, this study suggests that if players do go into a match or training session without replenishing their carbohydrate stores, then their sprint and skill performance may suffer, especially towards the end of the game.

Hypoglycemia has been suggested as a possible reason for the deterioration in performance in sports such as soccer, which require both tactical thinking and cooperative interaction between players (25). Welsh et al. (27) attempted to assess the benefits of ingesting a carbohydrate–electrolyte solution on cognition before and after their subjects performed the LIST. They report a decrease in Stroop test performance with duration of the LIST (time effect), with a tendency for performance in the carbohydrate trial to be better maintained (nonsignificant treatment effect). Similar findings were reported for the Profile of Mood States (POMS) scores; however, the *fatigue* subcomponent of the POMS was significantly lower after the run to fatigue in the carbohydrate trial. Their suggestion was that higher blood glucose may have maintained CNS functioning and, along with lower plasma FFA, may have lowered central fatigue mediators such as serotonin (27). In the current study, plasma glucose was maintained above resting values in the CHO-E trial, whereas in the PLA trial, plasma glucose concentrations fell from 30 min onwards to 3.9 mM at the end of the LIST (Fig. 5). It is reasonable to speculate that the lower glucose availability in the PLA trial may have had an influence on neuromuscular and/or CNS function, resulting in a less than optimal motor control during the skill tests. This may be part of the explanation for the greater increase in penalty time in the LSPT for the PLA trial (Table 2). Even though participants' glucose concentrations were significantly lower, though did not reach hypoglycemic values (< 3 mM (7)) in the PLA trial, it still remains to be elucidated as to the possible effects of low plasma glucose concentrations on cognitive function and skill performance. Furthermore, the greater availability of glucose as a substrate in the CHO-E trial may have contributed to the higher rate of carbohydrate oxidation, especially towards the end of exercise (Table 3). Thus, this contribution of carbohydrate to muscle and cerebral metabolism might explain not only maintenance of skill levels, but also sprint performance (Fig. 4), and the overall higher metabolic rate in the CHO-E trial (Table 3).

One of the key physical attributes a soccer player can possess is sprinting ability. In the current study, subjects were able to sprint faster in the CHO-E trial (Fig. 4), as also shown in previous studies using the LIST protocol (27). The effect size for 15-m sprint performance is 0.24 (Cohen's *d*), which is a "small" effect; however, in terms of practical significance, this ability to maintain better sprinting performance may differentiate those players who can, from those who cannot, reach the football and then perform the required skills. Indeed, the sprinting element of the LSST was sacrificed by players to maintain goal-scoring accuracy. The reason for this improvement in the CHO-E trial is thought to be attributable to the effects of the exogenous carbohydrate ingestion. Although soccer players can be adversely affected by dehydration (10), in the present study we found no difference in body mass loss (~1.4 kg, or about 1.8%) between the two trials or a difference in plasma volume (−3.3 and −4.1% in the CHO-E and PLA trials, respectively). Therefore, it seems unlikely that the differences in sprint performance and overall work rate were a consequence of differences in the degrees of dehydration between the two trials.

Although the participants were sprinting faster and working harder in the CHO-E condition, the RPE results suggest that they perceived they were exerting themselves to a greater extent in the PLA trial, especially so during the last block of exercise (17.4 ± 1.5 vs 16.6 ± 1.9, PLA vs CHO-E, $P < 0.01$). This also suggests that central fatigue has a major role in helping to explain performance decrements towards the end of exercise. Further work is required to elucidate why and to what extent carbohydrate ingestion during prolonged high-intensity exercise may have on perceived exertion, mood, and cognitive function.

In summary, even though subjects were sprinting faster in the CHO-E trial, thus resulting in a greater overall energy expenditure, skill performance was better maintained than in the PLA trial after exercise. Within a match situation, this would indicate that players would be able to sprint faster to get to the ball, and still have the ability to make an accurate pass or shot. Furthermore, participants seemed to be

unaware that they were exerting themselves to a greater extent in the CHO-E than in the PLA trial. Therefore, the results of this study suggest that ingestion of a carbohydrate–electrolyte solution, during prolonged, intermittent exercise, helps maintain soccer skill and sprint performance in players who start the game with reduced carbohydrate stores.

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REFERENCES

1. Abt, G., S. Zhou, and R. Weatherby. The effect of a high-carbohydrate diet on the skill performance of midfield soccer players after intermittent treadmill exercise. *J. Sci. Med. Sport* 1:203–212, 1998.
2. Ali, A., C. Williams, M. A. Hulse, et al. Reliability and validity of two tests of soccer skill. *J. Sports Sci.* 25:1461–1470.
3. Bangsbo, J. The physiology of soccer. *Acta Physiol. Scand.* 151(Suppl.):619, 1994.
4. Bergstrom, J., and E. Hultman. A study of the glycogen metabolism during exercise in man. *Scand. J. Clin. Lab. Inv.* 19:218–228, 1967.
5. Bowtell, J. L., K. Gelly, M. L. Jackman, A. Patel, M. Simeoni, and M. J. Rennie. Effect of oral glutamine on whole body carbohydrate storage during recovery from exhaustive exercise. *J. Appl. Physiol.* 86:1770–1777, 1999.
6. Clarke, N., B. Drust, D. MacLaren, and T. Reilly. Strategies for hydration and energy provision during soccer specific exercise. *Int. J. Sport Nutr. Exerc. Metab.* 15:625–640, 2005.
7. Costill, D. L. Nutrition and dietetics. In: *The Olympic Book of Sports Medicine*, A. Dirix, H. G. Knuttgen, and K. Tittel (Eds.). Oxford, UK: Blackwell Scientific Publications, pp. 603–644, 1988.
8. Davis, J., R. Welsh, and N. Alderson. Effects of carbohydrate and chromium ingestion during intermittent high-intensity exercise to fatigue. *Int. J. Sport Nutr. Exer. Metab.* 10:476–485, 2000.
9. Dill, D. B., and D. L. Costill. Calculation of percentage changes in volumes of blood, plasma and red cells in dehydration. *J. Appl. Physiol.* 37:247–248, 1974.
10. Fallowfield, J., C. Williams, J. Booth, B. Choo, and S. Growns. Effect of water ingestion on endurance capacity during prolonged running. *J. Sports Sci.* 14:497–502, 1996.
11. Fitts, P. M., and M. I. Posner. *Human Performance*. Belmont, CA: Brooks/Cole, pp. 109–112, 1967.
12. Hargreaves, M., P. Dillo, D. Angus, and M. Febbraio. Effect of fluid ingestion on muscle metabolism during prolonged exercise. *J. Appl. Physiol.* 80:363–366, 1996.
13. Jacobs, I. Lactate, muscle glycogen and exercise performance in man. *Acta Physiol. Scand. Suppl.* 495:1–35, 1981.
14. Kirkendall, D. Effects of nutrition on performance in soccer. *Med. Sci. Sports Exerc.* 25:1370–1374, 1993.
15. Kirkendall, D. Fluid and electrolyte replacement in soccer. *Clin. Sports Med.* 17:729–738, 1998.
16. McGregor, S. J., C. W. Nicholas, H. K. A. Lakomy, and C. Williams. The influence of intermittent high-intensity shuttle running and fluid ingestion on the performance of a soccer skill. *J. Sports Sci.* 17:895–903, 1999.
17. Nassis, G., C. Williams, and P. Chisnall. The effect of a carbohydrate-electrolyte drink on endurance capacity during prolonged intermittent high intensity running. *Br. J. Sports Med.* 32:248–252, 1998.
18. Nevill, M. E., G. C. Bogdanis, L. H. Boobis, H. K. A. Lakomy, and C. Williams. Muscle metabolism and performance during sprinting. In: *Biochemistry of Exercise IX*, R. J. Maughan and S. Shirreffs (Eds.). Champaign, IL: Human Kinetics, pp. 243–260, 1996.
19. Nicholas, C. W., C. Williams, H. K. A. Lakomy, G. Phillips, and A. Nowitz. Influence of ingesting a carbohydrate-electrolyte solution on endurance capacity during intermittent, high intensity shuttle running. *J. Sports Sci.* 13:283–290, 1995.
20. Nicholas, C. W., K. Tsintzas, L. Boobis, and C. Williams. Carbohydrate-electrolyte ingestion during intermittent high-intensity running. *Med. Sci. Sports Exerc.* 31:1280–1286, 1999.
21. Nicholas, C. W., F. E. Nuttall, and C. Williams. The Loughborough Intermittent Shuttle Test: a field test that stimulates the activity pattern of soccer. *J. Sports Sci.* 18:97–104, 2000.
22. Ramsbottom, R., J. Brewer, and C. Williams. A progressive shuttle run test to estimate oxygen uptake. *Br. J. Sports Med.* 22:141–144, 1988.
23. Romijn, J. A., E. F. Coyle, L. S. Sidossis, et al. Regulation of endogenous fat and carbohydrate metabolism in relation to exercise intensity and duration. *Am. J. Physiol.* 265:E380–E391, 1993.
24. Saltin, B. Metabolic fundamentals in exercise. *Med. Sci. Sports Exerc.* 5:137–146, 1973.
25. Shephard, R. J., and P. Leatt. Carbohydrate and fluid needs of the soccer player. *Sports Med.* 4:164–176, 1987.
26. Vollestad, N. K., K. I. Tabata, and J. L. Medbo. Glycogen breakdown in different human muscle fibre types during exercise of short duration. *Acta Physiol. Scand.* 144:135–141, 1992.
27. Welsh, R. S., J. M. Davis, J. R. Burke, and H. G. Williams. Carbohydrates and physical/mental performance during intermittent exercise to fatigue. *Med. Sci. Sports Exerc.* 34:723–731, 2002.
28. Zeederberg, C., L. Leach, E. V. Lambert, T. D. Noakes, S. C. Dennis, and J. A. Hawley. The effect of carbohydrate ingestion on the motor skill proficiency of soccer players. *Int. J. Sports Nutr.* 6:348–355, 1996.