Harper, Liam D., Stevenson, Emma, Rollo, Ian and Russell, Mark

The influence of a 12 per cent carbohydrate-electrolyte beverage on selfpaced soccer-specific exercise performance

Original Citation

Harper, Liam D., Stevenson, Emma, Rollo, Ian and Russell, Mark (2017) The influence of a 12 per cent carbohydrate-electrolyte beverage on selfpaced soccer-specific exercise performance. Journal of Science and Medicine in Sport. ISSN 1440-2440

Title: The influence of a 12 per cent carbohydrate-electrolyte beverage on self-paced soccer-specific exercise performance

Authors: Liam D. Harper, Emma J. Stevenson, Ian Rollo, Mark Russell

PII: S1440-2440(17)30399-7
DOI: http://dx.doi.org/doi:10.1016/j.jsams.2017.04.015
Reference: JSAMS 1513

To appear in: *Journal of Science and Medicine in Sport*

Received date: 31-10-2016
Revised date: 13-3-2017
Accepted date: 16-4-2017

Please cite this article as: Harper Liam D, Stevenson Emma J, Rollo Ian, Russell Mark.The influence of a 12 per cent carbohydrate-electrolyte beverage on self-paced soccer-specific exercise performance.*Journal of Science and Medicine in Sport* http://dx.doi.org/10.1016/j.jsams.2017.04.015

Manuscript title: The influence of a 12 per cent carbohydrate-electrolyte beverage on self-paced soccer-specific exercise performance

Running title: Carbohydrates and soccer performance

Liam D. Harper [a], Emma J. Stevenson [b], Ian Rollo [c], Mark Russell [d]

[a] Human and Health Sciences, University of Huddersfield, Huddersfield, United Kingdom

[b] Institute of Cellular Medicine, Newcastle University, Newcastle, United Kingdom

[c] The Gatorade Sports Science Institute, PepsiCo, United Kingdom

[d] School of Social and Health Sciences, Leeds Trinity University, Leeds, United Kingdom

Corresponding author: Dr Mark Russell

m.russell@leedstrinity.ac.uk

Abstract word count:	250 words
Manuscript word count:	3000 words
Figures:	2
Tables:	1

Abstract

Objectives: To assess the physiological and performance effects of a 12% carbohydrate-electrolyte beverage consumed at practically applicable time-points (i.e., before each half) throughout simulated soccer match-play.

Design: Randomised, crossover.

Methods: Fed players (*n*=15) performed 90-min of soccer-specific exercise (including self-paced exercise at the end of each half). Players consumed carbohydrate-electrolyte (CHO; 60 g·500 ml^{-1}, Na^{+} 205 mg·500 ml^{-1}), placebo-electrolyte (PL) or water (Wat) beverages at the end of the warm-up (250 ml) and half-time (250 ml plus ad-libitum water). Blood was drawn before each half and every 15-min during exercise. Physical (15-m sprinting, countermovement jumps, self-paced distance, acceleration/deceleration count), technical (dribbling) and cognitive (memory, attention, decision-making) performance was assessed. Ratings of perceived exertion (RPE) and abdominal discomfort were measured.

Results: Against Wat and PL, CHO increased (all $p<0.05$) mean accelerations >1.5 $m{\cdot}s^{-2}$ during self-paced exercise (>+25%) and dribbling speed from 60-min onwards (>+3%). Mean sprinting speed improved (+2.7%) in CHO versus Wat. Blood glucose increased before and during each half in CHO versus PL and Wat (all $p<0.05$). A 27% decline in glycaemia occurred at 60-min in CHO. RPE was comparable between trials. Cognition reduced post-exercise ($p<0.05$); this decline was not attenuated by CHO. Abdominal discomfort increased during exercise but was similar between trials.

Conclusions: Using more realistic fluid ingestion timings than have been examined previously, consuming a 12% carbohydrate-electrolyte beverage increased blood glucose, self-paced exercise performance, and improved dribbling speed in the final 30-min of exercise compared to water and placebo. Carbohydrates did not attenuate post-exercise reductions in cognition.

Keywords: football, skill, sucrose, maltodextrin, isomaltulose

Introduction

Soccer is a high-intensity intermittent sport played over two 45-min periods each separated by a half-time (HT) break. Over 90-min, physical and skilled performance declines throughout the second half [1-3]. To sustain glycaemia and fuel provision, and attenuate dehydration, 6-10% carbohydrate-electrolyte beverages are recommended to maintain osmotic balance and attenuate soccer-specific fatigue [4, 5]. Indeed, shooting performance was maintained when 6% sucrose-electrolyte beverages were consumed every 15-min (carbohydrate: ~59 $g \cdot h^{-1}$) during simulated match-play [1].

Carbohydrate-electrolyte beverages elicit ergogenic effects when consumed regularly throughout intermittent exercise [1, 6]. However, fluid intake during competitive soccer seldom occurs as often as has previously been examined (i.e., every 15-min); consumption may only occur during scheduled breaks in play (e.g., HT) [7]. The final stages of the warm-up and the immediate time-period preceding kick-off are supported empirically as fluid ingestion opportunities on match-day. As few studies have sought to replicate such ingestion patterns, it is unclear whether ergogenic effects of carbohydrate-electrolytes consumed throughout soccer-specific exercise persist when fluid ingestion patterns better reflect competitive demands.

Metabolic responses (i.e., blood glucose, carbohydrate and fat oxidation) appear comparable throughout intermittent exercise when equal amounts of carbohydrate (~68 g ingested at ~45 $g \cdot h^{-1}$) are consumed in two (i.e., before each half) or six (i.e., every 15-min) boluses [7]. Fewer ingestion opportunities likely make it harder to achieve carbohydrate consumption rates shown to be ergogenic (e.g., >50 $g \cdot h^{-1}$; [1, 8]) without also increasing gastro-intestinal distress. Indeed, gut fullness increased when fewer opportunities existed to consume carbohydrate-containing fluids [7]. Consuming electrolyte beverages that contain increased (>10%) concentrations of carbohydrates may provide a practical strategy for soccer players with limited opportunities to consume beverages before and during match-play.

The efficacy of carbohydrate-electrolyte beverages have primarily been examined using prescribed exercise intensities (reviewed in: [9, 10]). Compared to actual match-play where players may regulate their activity, omitting self-paced actions may limit the opportunity for self-selection of running speeds in order to preserve peripheral physiological functioning [11]. A paucity of research currently exists regarding the efficacy of carbohydrate-electrolyte ingestion using self-paced exercise protocols [12]. Accordingly, on occasions that better reflect competitive practices, this study aimed to provide carbohydrates throughout intermittent activity incorporating self-paced exercise. We hypothesised that ingesting 250 ml of a 12% carbohydrate-electrolyte beverage <15-min before starting each half would improve performance versus the ingestion of equivalent volumes of placebo or water beverages.

Methods

Following ethical approval and informed consent being attained, 15 male University soccer players (body mass: 75.7±7.7 kg, stature: 1.81±0.07 m, age: 22±2 years, estimated $\dot{V}O_{2\,max}$: 56±2 $ml \cdot kg^{-1} \cdot min^{-1}$, >1 year playing experience) completed the study. An additional participant was recruited who did not complete all experimental requirements due to issues unrelated to the study. All players attended preliminary visits ($\dot{V}O_{2\,max}$ estimation, procedural habituation) before three main trials (water; WAT, carbohydrate-electrolyte; CHO, placebo-electrolyte; PL, separated by >7 days). Players followed habitual diets (avoiding caffeine) and recorded all food consumed (analysed retrospectively; Nutritics, Nutritics Ltd., Dublin, Ireland) for 48h before trials. Players consumed the same evening meal the night before testing (energy content: 3.5 MJ, 101 g carbohydrates, 34 g fats, 27 g proteins) and refrained from strenuous physical activity for 72h before involvement. Environmental conditions were comparable (all $p>0.05$; temperature: 17.8±0.8°C, pressure: 1032±23 mmHg, humidity: 37±5%).

Preliminary trials required voiding before body mass (model 876; Seca Ltd, Birmingham, UK) and stature (Portable Stadiometer; Holtain Ltd, Wales, UK) measurement. A warm-up (~20 min; light aerobic activity, dynamic stretches, soccer skills, 20-m sprints) preceded the multistage fitness test (MSFT) [13] where a level score >12 was required for further participation. A second session habituated players with main trial procedures.

Players attended the laboratory at ~08:00 following overnight fasting. Urine osmolality (Model 3300 Micro-osmometer; Advanced Instruments Inc., Norwood, USA) was assessed on arrival and preceded capillary blood sampling (baseline). At ~08:15, a cereal (Rice Krispies; Kellogg's, UK) and semi-skimmed milk breakfast (~10% daily energy requirement) was consumed before mass and stature measurements. All players drank water (Highland spring; Highland Spring Group, Scotland) with the pre-exercise meal (500 ml).

Players remained rested for ~90 min (10:00) until blood was taken (rest). Cognition (~20 min; 10:05–10:25) was assessed (COMPASS; Northumbria University, UK) [14] and mean speed and accuracy scores (secondary and working memory, attention, and decision-making) and the number of correct and incorrect responses (immediate and delayed word recall) were determined. Thereafter, a standardised warm-up (detailed previously) was performed (10:30). A passive ten-min period preceded blood sampling (pre-exercise) and maximal countermovement jump (CMJ) height was assessed (10:55; OptoJump Next; Microgate SRL, Italy; three repetitions, separated by 10 s of intra-set recovery; CV<4% [15]) before exercise started (11:00). A 15-min passive recovery period (HT) separated two 45-min halves and post-exercise assessments of CMJ height, cognition, hydration status (via urine samples) and body mass preceded a standardised cool down.

Players performed 90-min of soccer-specific exercise (modified Soccer Match Simulation; SMS [16]) requiring audio-prescribed (ten blocks) and self-paced (four blocks) activity equally split across two halves. The original SMS is reliable [2, 15, 17] and requires various intensities of running, including backwards and sideward movements, over 20-m while performing 15-m sprints (Brower, USA) and 18-m ball dribbles. Players dribbled a ball between cones (3-m apart) towards video cameras (DCR-HC96E; Sony Ltd, UK) as fast and precisely as possible. Digitisation (Kinovea version 0.8.15; Kinovea Org., France) yielded speed (time taken to successfully complete) and precision (distance of the ball from each cone) data with a cone being unsuccessfully negotiated if touched by the ball or not completed in the required direction [17]. Dribbling performance was expressed per 15-min of exercise.

Performed at the end of each half, and in modification to the original SMS, self-paced exercise required the same duration and pattern of activity as the audio-prescribed component. Self-paced performance was determined by distance travelled (using calibrated video footage; ICC>0.99, CV<1%) and accelerometry (acceleration/deceleration counts over mutually exclusive thresholds; >1.5 $m \cdot s^{-2}$, >2.5 $m \cdot s^{-2}$, >3.5 $m \cdot s^{-2}$) via 10 Hz Global Positioning System units (Catapult Sports, Leeds, UK). A barrier separated players exercising in pairs to minimise inadvertent pacing.

Capillary blood was drawn at: baseline, rest, pre-exercise, HT, and 15-, 30-, 45-, 60-, 75-, and 90-min of exercise. Blood samples were analysed for lactate and glucose concentrations (Biosen C-Line, EKF Diagnostics, Germany). Urine-corrected mass changes and environmental conditions (ETHG-912; Oregon Scientific, USA) were determined pre- and post-exercise. Heart rate (HR) was continuously recorded (Polar RS400; Polar, Finland). Abdominal discomfort [18] and ratings of perceived exertion (RPE; 6-20) values [19] were obtained every 15-min.

Players consumed a carbohydrate-electrolyte (CHO), a flavour-matched placebo-electrolyte (PL) or a water (Wat) beverage in a cross-over fashion. Randomisation (www.randomization.com) was performed independently with researchers who recruited players being unaware of the allocated product sequence (concealed allocation). The CHO and PL beverages were ready-to-drink formulations (PepsiCo International Ltd., USA) matched for sweetness, containing comparable amounts of Na^+ (41 $mg \cdot 100\ ml^{-1}$), and were administered double-blind. The Wat beverage contained Na^+ (0.56 $mg \cdot 100\ ml^{-1}$). Beverages were ingested towards the end of the warm-up (250 ml) and at HT (250 ml); both <15-min before each half commenced. The CHO drink was a 12% solution delivering 60 g of carbohydrate per 500 ml from a blend of sucrose, maltodextrin and isomaltulose. Boluses of 250 ml of CHO were chosen according to empirical observations and pilot testing. PLA was non-caloric and taste-matched using artificial sweeteners. In trial one, water was consumed ad-libitum at HT (611±265 ml) and volumes were subsequently replicated. When asked, 33% of players correctly identified the CHO trial.

Statistical analysis was carried out using SPSS software (Version 21.0; SPSS Inc., IL). Results are reported as mean ± standard deviation (SD). Performance data (e.g., 15-m sprint times) represents a capture rate of 99.2%; the mean value of available data at the corresponding time-point replaced any missed data. Statistical significance was set at $p<0.05$. A two-way repeated measures analysis of variance established significant main effects in physiological and performance responses due to trial (time x trial interaction effects) and/or time (timing effects). Significant main effects of condition (trial effects) are only presented in cases where interaction effects are absent. Mauchly's test was consulted and Greenhouse–Geisser correction applied if the assumption of sphericity was violated. Partial eta-squared (η^2) values were calculated and LSD corrected post-hoc tests highlighted between-trial differences. Retrospective power analyses (G*Power v3.1.9.2; Universität Düsseldorf, Germany) highlighted that >80% statistical power existed for differences in blood glucose concentrations.

Results

Players arrived following similar ($p>0.05$) nutritional intakes (total energy: 8277±1809 $\text{kJ}\cdot\text{d}^{-1,}$ carbohydrates: 248±52 $\text{g}\cdot\text{d}^{-1}$, proteins: 85±34 $\text{g}\cdot\text{d}^{-1}$, fats: 76±26 $\text{g}\cdot\text{d}^{-1}$) and mean (156±8 $\text{beats}\cdot\text{min}^{-1}$) and peak (176±9 $\text{beats}\cdot\text{min}^{-1}$) HR was comparable between trials ($p>0.05$).

Trial ($p<0.001$, $\eta^2=0.442$) and time ($p<0.001$, $\eta^2=0.494$) influenced blood glucose concentrations (Figure 1A). Compared to PL, CHO raised blood glucose at pre-exercise, HT and 75-min (all $p<0.05$). Relative to Wat, CHO elevated blood glucose at pre-exercise, HT, 45- and 60-min (all $p<0.05$). Despite a 27% drop from HT values, blood glucose at 60-min was greater in CHO versus Wat ($p=0.038$) but not PL ($p=0.125$). No differences existed between PL and Wat.

Blood lactate concentrations increased ($p<0.001$, $\eta^2=0.781$) but were similar between trials ($p=0.228$, $\eta^2=0.090$). A main condition effect ($p=0.021$, $\eta^2=0.240$; Figure 1B) indicated that blood lactate values in PL were lower than CHO ($p=0.020$) and Wat ($p=0.044$). No differences existed between CHO and PL ($p=0.505$).

Urine osmlolality reduced pre- to post-exercise (826±181 mOsmol·kg^{-1} vs. 490±205 mOsmol·kg^{-1}; $p<0.001$, $\eta^2=0.807$) but was not affected by trial ($p=0.219$, $\eta^2=0.103$). Body mass loss was comparable ($p=0.429$, $\eta^2=0.059$) across trials (1.6±0.3 kg, 2.2±0.3%). Although abdominal discomfort (Figure 1C) increased ($p<0.001$, $\eta^2=0.418$), no trial effects occurred ($p=0.166$, $\eta^2=0.094$). Similarly, RPE (Figure 1D) was comparable between trials ($p=0.684$, $\eta^2=0.050$). Values increased from 0-15-min ($p<0.001$, $\eta^2=0.674$).

Sprint speed (Figure 2A) reduced ($p<0.001$, $\eta^2=0.650$) similarly across trials ($p=0.924$, $\eta^2=0.031$). However, condition effects highlighted that 15-m sprints were fastest ($p=0.002$, $\eta^2=0.365$) for CHO versus Wat (+2.7%, $p=0.004$) but not PL ($p=0.078$). Mean 15-m sprint speeds were also faster in PL versus Wat ($p=0.018$). Mean CMJ height (33.7±5.0 cm) was not influenced by trial ($p=0.257$, $\eta^2=0.093$) or time ($p=0.060$, $\eta^2=0.231$).

Self-paced distance covered decreased by 15-m in the second half (1428±31-m vs. 1413±45-m; $p=0.010$, $\eta^2=0.388$). Although comparable ($p=0.142$, $\eta^2=0.130$), the between-half decrements observed in PL (-18-m) and Wat (-26-m), appeared attenuated by CHO (+1-m). The number of self-paced accelerations >1.5, >2.5 and >3.5 m·s^{-2} were not affected by trial (all $p>0.05$) or time (all $p>0.05$); being, 7±4, 2±2, 1±2, respectively. A main condition effect highlighted that CHO increased the mean number of self-paced accelerations >1.5 m·s^{-2} (9±4, $p=0.027$, $\eta^2= 0.227$) versus PL (7±4) and Wat (6±4) by +25% ($p=0.038$) and +36% ($p=0.029$), respectively. No differences existed between Wat and PL ($p=0.481$) for the mean number of self-paced accelerations >1.5 m·s^{-2}. The number of self-paced decelerations >1.5, >2.5 and >3.5 m·s^{-2} were unaffected by trial (all $p>0.05$) or time (all $p>0.05$); being, 6±4, 1±1, 1±1, respectively.

Dribbling speed varied according to trial ($p=0.042$, $\eta^2=0.154$) and time ($p=0.008$, $\eta^2=0.252$). Dribbling speeds were similar between PL and WAT (all $p>0.05$), but CHO improved dribbling speed from 60-min onwards versus both PL and Wat ($p<0.040$; Figure 2B). Trial did not influence dribbling precision ($p=0.597$, $\eta^2=0.056$) and success ($p=0.055$, $\eta^2=0.117$) but timing throughout exercise did (p=0.048, η^2=0.163; p=0.033, η^2=0.156, respectively); dribbles at 75-90-min were ~8% more accurate versus 0-15-min (38±6 cm; p=0.011) and 6% more successful (p=0.008) than 60-75-min (91±11%).

Table 1 presents the cognition data. Reaction times in choice decision making, numeric working memory, and picture recognition improved post-exercise, but such responses occurred in the context of lower correct answers. The number of correct responses on delayed word recall tasks were also lower post-exercise but cognition was unaffected by drink (all p>0.05).

Discussion

The primary aim of this study was to examine the physiological and performance effects of a 12% carbohydrate-electrolyte drink consumed <15-min before starting each half of soccer-specific exercise. Carbohydrate ingestion improved soccer dribbling speed and self-paced exercise performance versus equivalent volumes of water and placebo. Relative to water, mean 15-m sprints were faster following carbohydrate ingestion. These data support previous observations where beneficial effects of exogenous energy provision result from consuming beverages more frequently than possible in soccer match-play (i.e., every 15-min). This was the first study to investigate the physiological and performance effects of providing appropriate quantities of carbohydrate and electrolytes in a manner which better replicates current practice in competitive soccer.

Improved sprinting (speed: +2.7% vs. Wat), soccer dribbling (speed: >+3% vs. Wat and PL) and self-paced exercise (mean number of self-paced accelerations >1.5 $m \cdot s^{-2}$: >+25% vs. Wat and PL) performance occurred throughout CHO; reflecting previous observations when carbohydrate was consumed in beverages [6], gels [20], or mouth rinses [12]. Despite improved high-intensity performance in CHO, no between-trial effects were observed for RPE. As RPE is thought to inform team sport pacing strategies [21], players could be exercising at higher intensities in CHO but not rating such exercise as being more challenging. The strategy of carbohydrate provision used in this study aligns to current recommendations [5] while also employing a logistically feasible feeding pattern.

Throughout self-paced exercise, players replicated the activity pattern performed in the audio-prescribed component. Any additional distance above the ~1440-m normally covered throughout two blocks of the SMS would initially have consisted of walking (as three 20-m walks commence each 4.5-min exercise block). Such low intensity activity may have muted the manifestation of more substantial between-trial differences in the *extra* self-paced exercise performed; likely explaining the similarity of the overall distances covered. That said, although non-significant, CHO (+1-m) appeared beneficial in attenuating the between-half decrements observed in PL (-18-m) and Wat (-26-m). To contextualise, a between-half difference of 26-m represents a ~1.8% reduction in the ~1440-m distance required by two audio-paced blocks of the SMS.

Previous studies report a speed-accuracy trade-off when skills were performed throughout soccer-specific exercise [1, 2]. Although no effects of CHO on cognition were observed, cognitive indices were impaired by 90-min of soccer-specific exercise (Table 1). As mental fatigue has been implicated in the reduction of soccer-specific performance [22], our findings support that intermittent exercise compromises aspects of technical, physical and cognitive performance even when players follow standard pre-game preparations. Notably, heart rate, sprint speed, body mass changes and blood lactate responses were reflective of match-play and previous studies using the SMS [1, 2, 16].

A 500 ml blend of sucrose, isomaltulose and maltodextrin was consumed in a 12% carbohydrate-electrolyte solution. The influence of each type of carbohydrate cannot be discerned due to the absence of single-source trials. Sports drink formulations often include electrolytes and two or more carbohydrates due to the increased oxidation rates seen when multiple sources (e.g., glucose and fructose) are consumed [23]. Ingesting Na^+ allows replacement of electrolyte losses occurring in sweat, maintenance of osmotic thirst and a continued drive to drink [24]. As dehydration is a candidate mechanism of fatigue in intermittent sprint performance [25], electrolyte differences between the Wat (Na^+: 0.56 $mg\cdot 100\ ml^{-1}$) and CHO and PL (both Na^+: 41 $mg\cdot 100\ ml^{-1}$) beverages may plausibly explain the differences in 15-m sprint speeds observed.

While the exact mechanisms are unclear, exogenous energy provision from carbohydrates during exercise improves performance and likely involves maintenance of blood glucose concentrations and carbohydrate oxidation rates, sparing of endogenous glycogen stores and, potentially, stimulation of reward centres via oropharyngeal receptor activation [26]. Relative to both Wat and PL, elevated blood glucose concentrations occurred in CHO immediately before, and throughout each 45-min half (Figure 1A). As the brain is primarily reliant on blood glucose concentrations as a fuel for cognition, the increased blood glucose concentrations at 60- and 75-min may offer an explanation for the improved dribbling speed observed [27]. Likewise, the absence of between-trial differences in blood glucose concentrations at 90-min may explain the lack of detectable post-exercise cognition effects for CHO. However, in the absence of cerebral glucose measurement, these proposed mechanisms should be interpreted with caution. Nevertheless, this study supports findings of impaired physical, technical and cognitive performance in the latter stages of soccer-specific exercise and the enhancement of selected physical and technical performance markers following carbohydrate supplementation [1, 6, 20].

Carbohydrate-electrolyte beverages ingested before and throughout each half of soccer-specific exercise have been shown to elicit transient reductions in glycaemia at 45-60-min which persists for most of the second half [1, 6]. This exercise-induced rebound glycaemic response also occurs when carbohydrates in the form a 12% beverage are provided less frequently (i.e., <15-min before commencing each half). This response probably reflects differences between the physiological effects of carbohydrates consumed in passive (i.e., HT; insulin secretion attempts to normalise blood glucose concentrations) versus active (i.e., warm-up; counter-regulatory hormones dampen the insulin response) states combined with post-exercise insulin-independent glucose uptake. Notably, mean glucose concentrations in the second half of CHO exceeded those observed in PL at 75-min; a novel finding versus previous work [1, 6]. While the effects of rapid reductions in glycaemia are unclear in team sports, evidence from primarily cycling studies do not support negative effects of rebound hypoglycaemia on physical performance markers [28].

Conclusions

Providing 60 g of carbohydrate via ingestion of a 12% beverage at the end of the warm-up and at half-time (with ad-libitum water intake) improved aspects of dribbling (i.e., speed) and self-paced soccer-specific exercise performance in the latter stages of soccer-specific exercise when compared to equivalent volumes of water and placebo. Further studies which better reflect the drinking practices and timing of carbohydrate intake during competitive soccer are required.

Practical Implications

- Soccer-specific exercise impaired physical, technical and cognitive performance despite players starting exercise in a fed state.
- Drinking 250 ml of a 12% carbohydrate-electrolyte beverage towards the end of the warm-up and at half-time (plus ad-libitum water ingestion), provided a practical hydro-nutritional strategy for soccer players without further compromising abdominal discomfort when compared to water.
- If carbohydrate-electrolyte beverages are recommended for the purposes of maintaining blood glucose concentrations, practitioners should be cognisant of transient reductions in glycaemia that occurred throughout the initial stages of the second half despite carbohydrate-electrolyte consumption.

Acknowledgements

We wish to thank Rachel Veasey for her assistance throughout the project and Sport Central (Newcastle-upon-Tyne) for facility use. This study was externally funded by PepsiCo Inc. IR is an employee of the Gatorade Sports Science Institute, a division of PepsiCo Inc. The views expressed in this manuscript are those of the authors and do not necessarily reflect the position or policy of PepsiCo Inc.

References

1. Russell M, Benton D, Kingsley M. Influence of carbohydrate supplementation on skill performance during a soccer match simulation. J Sci Med Sport 2012; 15(4):348-354.

2. Russell M, Benton D, Kingsley M. The effects of fatigue on soccer skills performed during a soccer match simulation Int J Sports Physiol Perform 2011; 6(2):221-233.

3. Russell M, Rees G, Kingsley MI. Technical demands of soccer match play in the English championship. J Strength Cond Res 2011; 27(10):2869-2873.

4. Convertino VA, Armstrong LE, Coyle EF et al. American College of Sports Medicine position stand - Exercise and fluid replacement. Med Sci Sports Exerc 1996; 28(1):R1-R7.

5. Thomas DT, Erdman KA, Burke LM. American College of Sports Medicine joint position statement. Nutrition and athletic performance. Med Sci Sports Exerc 2016; 48(3):543-568.

6. Kingsley M, Penas-Ruiz C, Terry C et al. Effects of carbohydrate-hydration strategies on glucose metabolism, sprint performance and hydration during a soccer match simulation in recreational players. J Sci Med Sport 2014; 17(2):239-243.

7. Clarke ND, Drust B, Maclaren DP et al. Fluid provision and metabolic responses to soccer-specific exercise. Eur J Appl Physiol 2008; 104(6):1069-1077.

8. Ali A, Williams C. Carbohydrate ingestion and soccer skill performance during prolonged intermittent exercise. J Sports Sci 2009: 27(14):1499-1508.

9. Russell M, Kingsley M. Influence of exercise on skill proficiency in soccer. Sports Med 2011; 41(7):523-539.

10. Williams C, Rollo I. Carbohydrate nutrition and team sport performance. Sports Med 2015; 45 Suppl 1:S13-S22.

11. Highton J, Twist C, Lamb K et al. Carbohydrate-protein coingestion improves multiple-sprint running performance. J Sports Sci 2013; 31(4):361-369.

12. Rollo I, Homewood G, Williams C et al. The influence of carbohydrate mouth rinse on self-selected intermittent running performance. Int J Sport Nutr Exerc Metab 2015; 25(6):550-558.

13. Ramsbottom R, Brewer J, Williams C. A progressive shuttle run test to estimate maximal oxygen uptake. Br J Sports Med 1988; 22(4):141-144.

14. Veasey RC, Gonzalez JT, Kennedy DO et al. Breakfast consumption and exercise interact to affect cognitive performance and mood later in the day. A randomized controlled trial. Appetite 2013; 68:38-44.

15. Harper LD, Hunter R, Parker P et al. Test-retest reliability of physiological and performance responses to 120 minutes of simulated soccer match-play. J Strength Cond Res 2016; 30(11):3178-3186.

16. Russell M, Rees G, Benton D et al. An exercise protocol that replicates soccer match-play. Int J Sports Med 2011; 32(7):511-518.

17. Russell M, Benton D, Kingsley M. Reliability and construct validity of soccer skills tests that measure passing, shooting, and dribbling. J Sports Sci 2010; 28(13):1399-1408.

18. Price M, Moss P, Rance S. Effects of sodium bicarbonate ingestion on prolonged intermittent exercise. Med Sci Sports Exerc 2003; 35(8):1303-1308.

19. Borg GAV. Perceived exertion - Note on history and methods. Med Sci Sports Exerc 1973; 5(2):90-93.

20. Harper LD, Briggs MA, McNamee G et al. Physiological and performance effects of carbohydrate gels consumed prior to the extra-time period of prolonged simulated soccer match-play. J Sci Med Sport 2016; 19(6):509-14.

21. Edwards AM, Noakes TD. Dehydration: cause of fatigue or sign of pacing in elite soccer? Sports Med 2009; 39(1):1-13.

22. Smith MR, Coutts AJ, Merlini M et al. Mental fatigue impairs soccer-specific physical and technical performance. Med Sci Sports Exerc 2016; 48(2):267-276.

23. Jeukendrup AE, Jentjens R. Oxidation of carbohydrate feedings during prolonged exercise: current thoughts, guidelines and directions for future research. Sports Med 2000; 29(6):407-424.

24. Baker LB, Munce TA, Kenney WL. Sex differences in voluntary fluid intake by older adults during exercise. Med Sci Sports Exerc 2005; 37(5):789-796.

25. Davis JK, Laurent CM, Allen KE et al. Influence of dehydration on intermittent sprint performance. J Strength Cond Res 2015; 29(9):2586-2593.

26. Cermak NM, van Loon LJ. The use of carbohydrates during exercise as an ergogenic aid. Sports Med 2013; 43(11):1139-1155.

27. Duelli R, Kuschinsky W. Brain glucose transporters: relationship to local energy demand. News Physiol Sci 2001; 16:71-76.

28. Jeukendrup AE, Killer SC. The myths surrounding pre-exercise carbohydrate feeding. Ann Nutr Metab 2010; 57 Suppl 2:18-25.

Figure legends

Figure 1: Mean ± SD blood glucose concentrations (A), blood lactate concentrations (B), abdominal discomfort values (C) and rating of perceived exertion values (D) throughout placebo-electrolyte (PL; thin black line), carbohydrate-electrolyte (CHO; bold black line) and water (Wat; dashed line) trials. * represents significant between-trial differences at corresponding time-point. X represents main effect of condition. HT represents half-time.

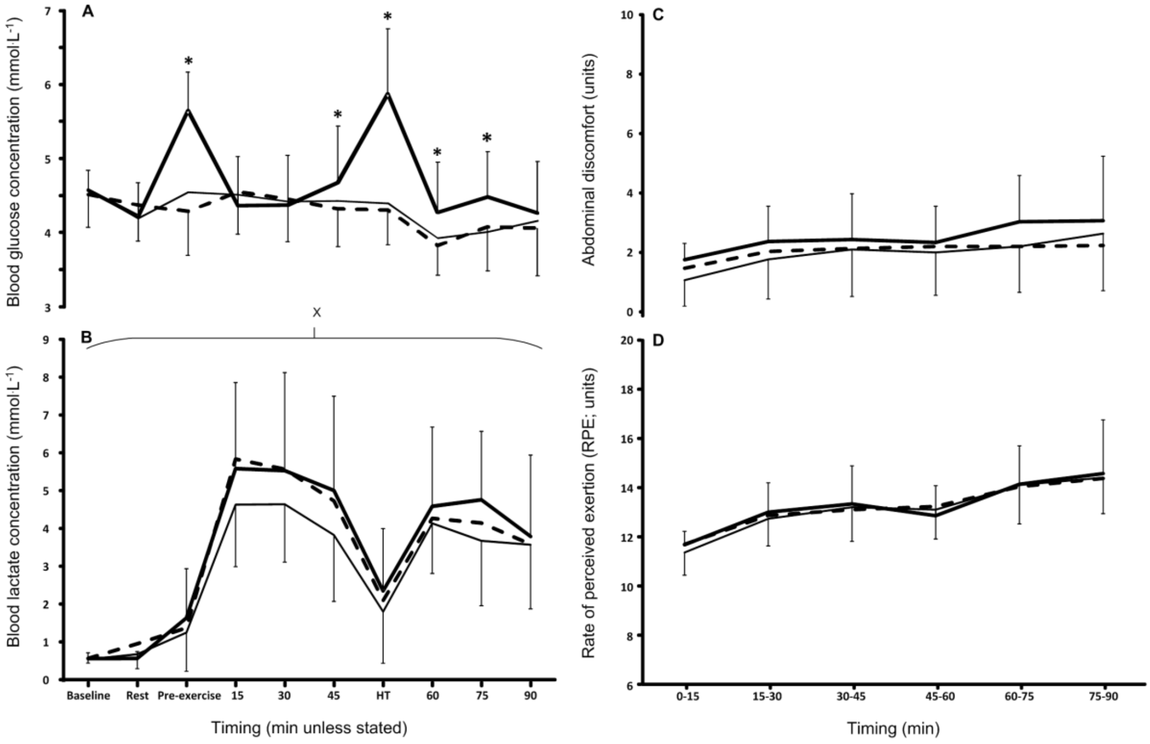

Figure 2: Mean ± SD 15-m sprint speed (A) and dribbling speed (B) throughout placebo-electrolyte (PL; thin black line), carbohydrate-electrolyte (CHO; bold black line) and water (Wat; dashed line) trials. * represents significant between-trial differences at corresponding time-point. X represents main effect of condition.

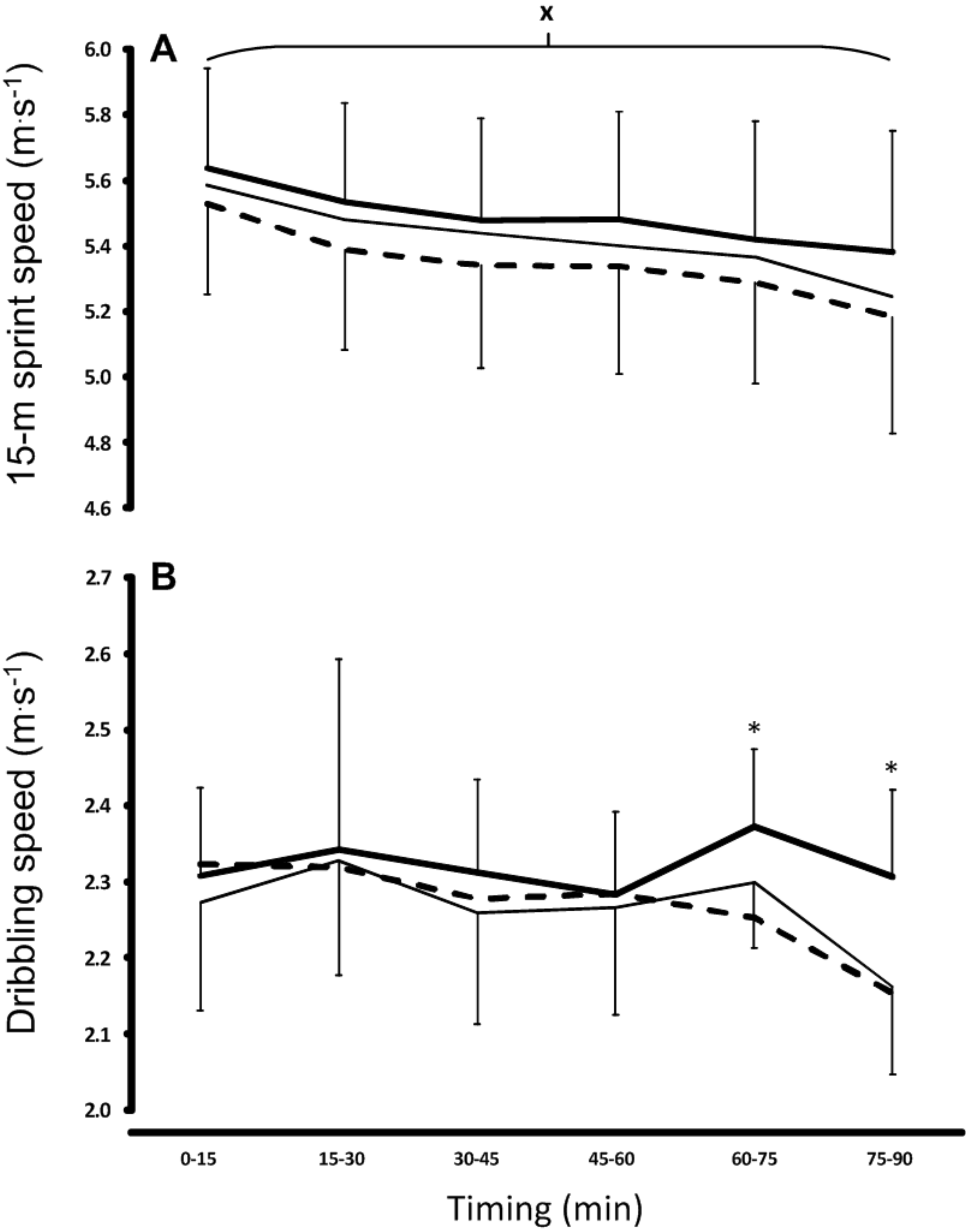

Table 1: Cognitive performance (mean ± SD) throughout carbohydrate-electrolyte (CHO), placebo-electrolyte (PL) and water (Wat) trials. * represents significant time effect

Component	**Variable**	**Trial**	**Pre-exercise**	**Post-exercise**	**Time x trial interaction (p), η^2**	**Time effect (p), η^2**
Choice decision making	% correct	PL	96 ± 2	95 ± 4	0.417, 0.061	0.044*, 0.259
		CHO	96 ± 3	95 ± 3		
		Wat	97 ± 3	96 ± 3		
	Reaction time (ms)	PL	396 ± 50	379 ± 39	0.599, 0.027	0.016*, 0.349
		CHO	400 ± 63	383 ± 57		
		Wat	399 ± 42	391 ± 50		
Rapid visual information processing	% correct	PL	55 ± 24	50 ± 23	0.072, 0.171	0.560, 0.025
		CHO	51 ± 22	54 ± 21		
		Wat	54 ± 20	54 ± 21		
	Reaction time (ms)	PL	498 ± 37	491 ± 51	0.244, 0.096	0.091, 0.191
		CHO	515 ± 62	488 ± 37		
		Wat	494 ± 41	487 ± 37		
Numeric working memory	% correct	PL	96 ± 3	93 ± 8	0.471, 0.052	0.037*, 0.274
		CHO	97 ± 4	94 ± 7		
		Wat	96 ± 4	96 ± 4		
	Reaction time (ms)	PL	891 ± 224	812 ± 217	0.912, 0.007	<0.001*, 0.634
		CHO	849 ± 226	787 ± 193		
		Wat	877 ± 244	802 ± 169		
Picture recognition	% correct	PL	88 ± 13	87 ± 12	0.413, 0.061	0.034*, 0.284
		CHO	88 ± 8	85 ± 15		
		Wat	90 ± 10	84 ± 16		
	Reaction time (ms)	PL	873 ± 135	837 ± 154	0.160, 0.123	<0.001*, 0.638
		CHO	928 ± 208	812 ± 164		
		Wat	884 ± 105	820 ± 106		
Word recognition	% correct	PL	79 ± 7	77 ± 8	0.580, 0.038	>0.99, <0.001
		CHO	76 ± 8	78 ± 8		
		Wat	77 ± 10	77 ± 11		
	Reaction time (ms)	PL	942 ± 197	855 ± 173	0.561, 0.040	0.002*, 0.512
		CHO	954 ± 167	832 ± 146		
		Wat	1035 ± 248	885 ± 168		
Immediate word recall	Number correct	PL	7 ± 2	7 ± 2	0.327, 0.077	0.119, 0.165
		CHO	7 ± 2	6 ± 3		
		Wat	8 ± 2	7 ± 2		
	Number incorrect	PL	1 ± 1	1 ± 1	0.622, 0.033	0.622, 0.033
		CHO	1 ± 1	1 ± 1		
		Wat	0 ± 1	1 ± 1		
Delayed word recall	Number correct	PL	5 ± 2	5 ± 2	0.525, 0.045	<0.001*, 0.570
		CHO	5 ± 2	4 ± 2		
		Wat	6 ± 2	4 ± 2		
	Number incorrect	PL	1 ± 1	1 ± 1	0.908, 0.007	0.719, 0.010
		CHO	1 ± 1	1 ± 1		
		Wat	1 ± 1	1 ± 1		