

# Ingesting a 12% Carbohydrate-Electrolyte Beverage Before Each Half of a Soccer Match Simulation Facilitates Retention of Passing Performance and Improves High-Intensity Running Capacity in Academy Players

Paola Rodriguez-Giustiniani  
University of Stirling

Ian Rollo  
Gatorade Sports Science Institute

Oliver C. Witard and Stuart D. R. Galloway  
University of Stirling

This study investigated the influence of ingesting a 12% carbohydrate plus electrolyte (CHO-E) solution providing 60 g of carbohydrate before each half of a 90-min soccer match simulation (SMS) protocol on skill performance, sprint speed, and high-intensity running capacity. Eighteen elite academy (age:  $18 \pm 2$  years) soccer players ingested two 250-ml doses (pre-exercise and at halftime) of a 12% CHO-E solution or electrolyte placebo administered in a double-blind randomized cross-over design. During an indoor (artificial grass pitch) SMS, dribbling, passing, and sprint performance were assessed, and blood was drawn for glucose and lactate analysis. High-intensity running capacity was assessed following the SMS. Dribbling speed/accuracy and sprint speed remained unchanged throughout the SMS. Conversely, passing accuracy for both dominant (mean percentage difference [95% confidence interval, CI]: 9 [3, 15]) and nondominant (mean percentage difference [95% CI]: 13 [6, 20]) feet was better maintained during the SMS on CHO-E ( $p < .05$ ), with passing speed better maintained in the nondominant foot (mean percentage difference [95% CI]: 5.3 [0.7, 9.9],  $p = .032$ ). High-intensity running capacity was greater in CHO-E versus placebo (mean percentage difference [95% CI]: 13 [6, 20],  $p = .010$ ). Capillary blood glucose concentration was higher in CHO-E than placebo at halftime (CHO-E:  $5.8 \pm 0.5$  mM vs. placebo:  $4.1 \pm 0.4$  mM,  $p = .001$ ) and following the high-intensity running capacity test (CHO-E:  $4.9 \pm 0.4$  mM vs. placebo:  $4.3 \pm 0.4$  mM,  $p = .001$ ). Ingesting a 12% CHO-E solution before each half of a match can aid in the maintenance of soccer-specific skill performance, particularly on the nondominant foot, and improves subsequent high-intensity running capacity.

**Keywords:** exercise, football, metabolism, skill

Soccer is characterized by prolonged intermittent activities involving multiple sprints, high-intensity actions, and technical motor skills. As a result, fatigue in soccer is a complex phenomenon underpinned by central and physiological mechanisms, and is most prominent during the latter stages of a match (Mohr et al., 2005; Reilly, 1997). At the metabolic level, the decline in muscle glycogen content during a soccer match (Krustrup et al., 2006) is associated with a reduced work rate (Ostojic & Mazic, 2002). As the brain is dependent on a supply of blood glucose (Duelli & Kuschinsky, 2001), enhancing exogenous carbohydrate availability could preserve central nervous system (CNS) integrity (Meeusen & Decroix, 2018) and help to attenuate the loss of motor

skill performance (Russell et al., 2012). Moreover, the benefit of carbohydrate feeding on peripheral fatigue during intermittent exercise is evidenced by the previously reported better maintenance of high-intensity running capacity (McGregor et al., 1999).

Several studies have demonstrated that consuming carbohydrate beverages before and at regular intervals during sporting activities improves subsequent high-intensity exercise capacity (Davis et al., 2000; Kingsley et al., 2014; Nicholas et al., 1995; Phillips et al., 2012) and can also aid the retention of skill performance (Harper et al., 2017). This benefit of carbohydrate feeding has been demonstrated in soccer (Ali et al., 2007; Currell et al., 2009; Russell et al., 2012) and in other skill-based sports, such as tennis (McRae & Galloway, 2012) and squash (Bottoms et al., 2007), where weaker shots on the backhand side were most affected. In relation to soccer, from a practical perspective, carbohydrate beverages can only be supplied to players during the warm-up and during scheduled breaks in play (Clarke et al., 2008). Thus, opportunities available for soccer players to ingest sufficient carbohydrates ( $\sim 30$ – $60$  g·hr<sup>-1</sup>) are limited (Ali & Williams, 2009; Cermak & van Loon, 2013).

Rodriguez-Giustiniani, Witard, and Galloway are with the Faculty of Health Sciences and Sport, Physiology, Exercise and Nutrition Research Group, University of Stirling, Stirling, Scotland, United Kingdom. Rollo is with Gatorade Sports Science Institute, PepsiCo Global Nutrition R&D, Leicester, United Kingdom. Address author correspondence to Stuart D. R. Galloway at [s.d.r.galloway@stir.ac.uk](mailto:s.d.r.galloway@stir.ac.uk).

A potential strategy to overcome the limited opportunities to consume carbohydrates during soccer match-play is to administer highly concentrated carbohydrate beverages. In this context, the negative consequences of ingesting concentrated carbohydrate solutions on gastrointestinal comfort (Clarke et al., 2008) can be partially alleviated by the ingestion of maltodextrin plus fructose combinations (Jeukendrup, 2010; O'Brien & Rowlands, 2011). Accordingly, a recent study simulated a real-world soccer context by providing soccer players with a highly concentrated (12%) maltodextrin:fructose formulation at the end of the warm-up and at halftime (Harper et al., 2017). Skill performance and intermittent endurance performance were improved on the 12% carbohydrate trial compared with placebo, as evidenced by the maintenance of dribbling speed and self-paced soccer-specific exercise performance during the latter stages of the soccer match simulation (SMS; Harper et al., 2017). Crucially, players reported minimal gastrointestinal discomfort despite the provision of a 12% concentrated carbohydrate solution.

Although an excellent study, the work of Harper et al. (2017) does raise several applied questions. First, the impact of carbohydrate ingestion per se was not isolated because the players also were dehydrated by ~2% body mass during both trials. Second, participants ingested only a small standardized breakfast ~135 min before exercise, and performed the match simulation in the morning rather than in the afternoon, when professional youth team games or senior fixtures are normally scheduled in Scotland. Third, participants were University standard soccer players rather than young professionals, and no assessment of skill performance was performed on dominant and nondominant feet. To follow up the preliminary work of Harper et al. (2017), we set out to control for many of these additional factors, that is, maintain body mass loss within 1%, adopt prematch feeding guidelines prior to an afternoon kickoff, assess outcomes in professional youth players, and distinguish between potential effects in dominant and nondominant feet. Therefore, the primary aim of this study was to provide further practical insight into the influence of ingesting a 12% carbohydrate-electrolyte (CHO-E) beverage on soccer skill performance and high-intensity running capacity in professional youth academy soccer players. We hypothesized that ingesting 250 ml of a 12% CHO-E beverage before kickoff and during the halftime period, versus the ingestion of an equivalent volume of a placebo-electrolyte beverage, would improve the retention of soccer-specific skills (dribbling speed and accuracy, passing speed and accuracy), sprint speed, and anaerobic endurance running capacity during and after a 90-min SMS conducted in a cool environment.

## Methods

### Participants

A total of 18 male well-trained soccer players (seven midfielders, six defenders, and five strikers) were recruited from local soccer academies to participate in this investigation. A priori, we conducted a power calculation (using software G\*Power version 3, Düsseldorf, Germany) of appropriate sample size based on previously published data (Harper et al., 2017). This calculation revealed that 14 participants (using a cross-over design) were required for 80% power with a mean difference in skill performance score of  $0.8 \times SD$  and significance set at  $p < .05$ . All players had five or more years of playing experience, had been training consistently for 1 year or more, and were free from injury at the time of the recruitment and testing (age:  $18 \pm 2$  years, body mass:  $73.4 \pm$

$6.0$  kg, stature:  $177.7 \pm 4.8$  cm, body mass index:  $23.1 \pm 1.0$  kg·m<sup>-2</sup>, and estimated VO<sub>2</sub>max:  $55.9 \pm 1.5$  ml·kg<sup>-1</sup>). The experimental procedures were approved by the University of Stirling research ethics committee.

### Study Design

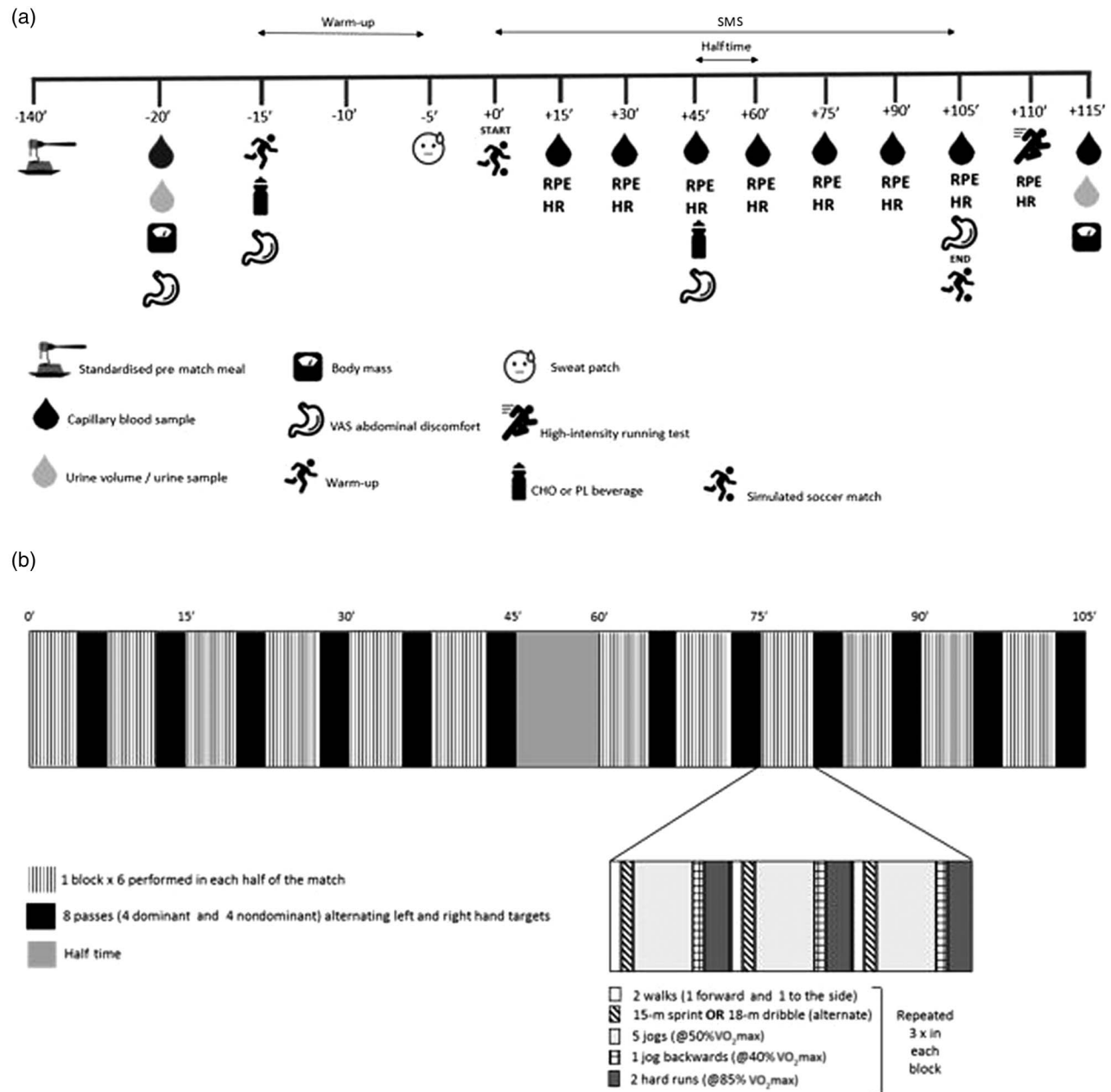
Players attended two preliminary study visits (VO<sub>2</sub>max estimation and full trial familiarization) before undertaking two main trials (CHO-E and placebo) with beverages administered in a double-blind randomized, cross-over manner. All visits were separated by 7–14 days. A shuttle running test protocol was used to estimate VO<sub>2</sub>max (Yo-Yo IR1; Bangsbo et al., 2008), with the level obtained used to determine the speed corresponding to 40%, 50%, 85%, and 90% of VO<sub>2</sub>max for use during and after the SMS protocol. Players followed 48-hr habitual diets (avoiding caffeine and alcohol) and recorded food consumed (analyzed retrospectively; Nutritics; Nutritics Ltd., Dublin, Ireland) before the familiarization visit. The prefamiliarization trial diet was replicated for both main trials. Players refrained from strenuous exercise 24 hr before the familiarization trial and main trial days. On the familiarization visit, players undertook a 10-min warm-up (incorporating light aerobic activity, dynamic stretches, and 20-m sprints), before completing the 90-min SMS protocol (Russell et al., 2011) followed by a high-intensity (90% VO<sub>2</sub>max) running test to exhaustion. All testing sessions were performed on an indoor artificial grass pitch.

### Experimental Trials

Experimental trials were scheduled to start in the afternoon to reflect times at which this cohort typically engages in soccer matches (Figure 1a). At the training ground, researchers provided players with a standardized breakfast (two eggs, two slices of bread, and one medium-sized banana, providing 423 kcal, 46-g carbohydrate, 26-g protein, and 14-g fat) and then a pretrial standardized meal 2 hr before beginning the main trials providing  $459 \pm 97$  kcal, 2-g carbohydrate·kg<sup>-1</sup> of body mass (pasta in a tomato sauce) plus 500 ml of water.

Soccer players performed the 90-min SMS that incorporates six blocks of activity equally split across two 45-min periods (Figure 1b). To assess dribbling performance, players dribbled a ball between six cones (3 m apart) toward a camera as fast and precisely as possible. For the sprint assessment, players ran as fast as possible through timing gates (Brower timing system, Draper, UT) placed 15 m apart, with a 1-m run-in. At the end of each of the 12 blocks of activity, players directed alternate passes toward target zones (2.0 m × 1.0 m) placed to the left and right at a distance of 7.9 m. The passing target was divided into three equally sized areas, with the center area worth ten points and the two areas at either side worth five points. Passes that missed the areas on the target were scored as zero. The bouts of passing consisted of eight passes (four with the dominant foot followed by four with the nondominant foot).

Digitization (Kinovea version 0.8.15; www.kinovea.org) yielded dribbling speed, dribbling precision, passing accuracy, and passing speed. Dribbling, sprint, and passing performance were expressed as means for each 15-min of the protocol. After the SMS protocol was completed, players performed a fixed high-intensity running capacity test to the point of volitional fatigue. The test consisted of 20-m shuttles at a speed corresponding to 90% of their VO<sub>2</sub>max until volitional exhaustion (the duration of the test



**Figure 1** — Schematic diagram of study protocol (a) and outline of the SMS protocol (b). SMS = soccer match simulation; RPE = ratings of perceived exertion (Borg, 1973); HR = heart rate; VAS = visual analogue scale; CHO = carbohydrate; PL = placebo.

ranged from 1 min 21 s to 1 min 42 s). Exhaustion was defined as the inability to maintain the required pace for two consecutive shuttles. Running capacity performance was expressed as the total running distance completed during the test. Following completion of exercise, body mass loss was calculated from the difference between pre-exercise and post-exercise body mass (SECA Quadra 808, Hamburg, Germany), corrected for fluid intake and urine output. Abdominal discomfort ratings (nausea, fullness, and bloatedness) were assessed routinely by asking players to place a vertical line on a 100-mm visual analogue scale.

Beverages (250 ml) were ingested on two separate occasions. First, 15 min before beginning the SMS and, second, immediately upon completing the first half (15 min before beginning the second half). The CHO-E and placebo beverages were ready to drink

formulations (PepsiCo International Ltd, Harrison, NY), matched for flavor, color, and texture, containing comparable amounts of  $\text{Na}^+$  (41 mg·100 ml<sup>-1</sup>). The CHO-E drink was a 12% solution (blend of maltodextrin and sucrose, 60 g·500 ml<sup>-1</sup>, Gatorade Football Energy; PepsiCo Inc.) delivering 40 g of carbohydrate per hour during the SMS. The placebo drink was noncaloric and taste matched using artificial sweeteners. Although water was made available ad libitum, no player consumed any water during either trial.

### Analytical Procedures

Capillary blood samples (30  $\mu\text{l}$  aliquots) were dispensed into 300  $\mu\text{l}$  of ice-cold 0.3-N perchloric acid, and shaken vigorously,

before being placed in an ice bath. On completion of the trial, samples were centrifuged and stored at  $-70^{\circ}\text{C}$  until analysis. Analyses of blood glucose and lactate concentrations were completed using the method of Maughan (1982). Urine samples were collected into a 0.5-L plastic container, and total mass (to the nearest 0.1 g) was assessed to determine urine volume. A 5 ml aliquot was then dispensed into a plain screw-cap tube and stored at  $4^{\circ}\text{C}$  until analysis of osmolality on the evening of the trial days (freezing point depression method; Löser Micro-Digital Osmometer M15, Schwerte, Germany).

## Statistical Analysis

Data are presented as mean (*SD*) with 95% confidence intervals (CIs) for mean differences shown in the text. Statistical significance was set at  $p < .05$ . Effect sizes based on using Cohen's *d* with threshold values for trivial, small, moderate, large, very large, and extremely large effects set at  $<0.2$ , 0.2, 0.6, 1.2, 2.0, and 4.0 (Hopkins et al., 2009) were reported, along with a written description. Performance variables were analyzed using two-way repeated measures analysis of variance whenever data contained multiple time points. When a significant Time  $\times$  Trial interaction was observed, post hoc pairwise comparisons with Bonferroni confidence interval adjustment were performed to identify at what time point(s) differences existed between conditions. If no Time  $\times$  Trial interaction was observed, main time or trial effects only were reported. Paired samples *t* tests were used to examine mean differences between trials when data were collected at one time point only (e.g., high-intensity anaerobic endurance running capacity).

## Results

No significant trial order effect was observed for any performance variable, therefore, any differences between conditions were considered to be due to treatment effects. Two out of the 18 participants correctly identified the order of the treatments. Dietary analysis revealed no difference in nutritional intake between CHO-E (total energy:  $2120 \pm 532 \text{ kcal}\cdot\text{d}^{-1}$ ; carbohydrates:  $290 \pm 63 \text{ g}\cdot\text{d}^{-1}$ ; proteins:  $101 \pm 47 \text{ g}\cdot\text{d}^{-1}$ ; fats:  $70 \pm 17 \text{ g}\cdot\text{d}^{-1}$ ) and placebo (total energy:  $2345 \pm 437 \text{ kcal}\cdot\text{d}^{-1}$ ; carbohydrates:  $293 \pm 62 \text{ g}\cdot\text{d}^{-1}$ ; proteins:  $89 \pm 27 \text{ g}\cdot\text{d}^{-1}$ ; fats:  $87 \pm 27 \text{ g}\cdot\text{d}^{-1}$ ; all  $ps > .05$ ) trials in the 48-hr period before the main experimental trial days. Ambient temperature (CHO-E:  $6 \pm 1^{\circ}\text{C}$  and placebo:  $6 \pm 1^{\circ}\text{C}$ ) and humidity (CHO-E:  $59 \pm 10\%$  and placebo:  $61 \pm 13\%$ ) were similar between trials ( $p > .05$ ).

## Physiological Responses to Soccer Match Simulation

There was no significant Time  $\times$  Trial interaction for heart rate, ratings of perceived exertion, and hydration status responses to the SMS ( $p > .05$ ). Heart rate increased from the 15-min time point ( $144 \pm 9 \text{ bpm}$ , CHO-E and placebo trials combined) throughout the SMS protocol (time effect:  $p = .01$ ), rising to  $158 \pm 6 \text{ bpm}$  (CHO-E and placebo combined) by the end (90 min) of the SMS protocol, with no difference between trials ( $p = .42$ ). Likewise, ratings of perceived exertion scores increased from the 15-min time point ( $10 \pm 2$ , CHO-E and placebo trials combined) throughout the SMS protocol (time effect:  $p = .01$ ), rising to  $15 \pm 3$  (CHO-E and placebo combined) by the end (90 min) of the SMS protocol, with no difference between trials ( $p = .17$ ). No differences were observed for any of the fluid balance and hydration status variables recorded

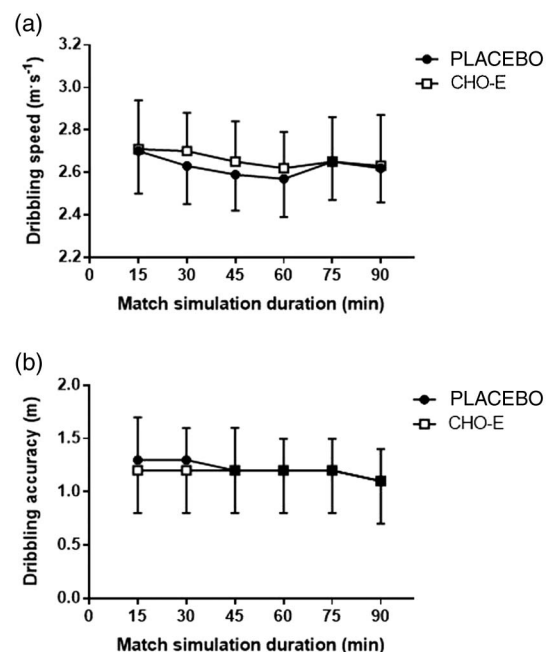
before and after the SMS protocol (pretrial urine osmolality:  $513 \pm 159 \text{ mOsm}\cdot\text{kg}^{-1}$ ; post-trial urine osmolality:  $464 \pm 137 \text{ mOsm}\cdot\text{kg}^{-1}$ ; body mass loss:  $0.7 \pm 0.4\%$ , all  $ps > .05$  for CHO-E and placebo trials combined).

## Dribbling Speed and Accuracy

Dribbling speed did not decline throughout the SMS on both CHO-E and placebo trials (Figure 2a), with no Time  $\times$  Trial interaction ( $p = .42$ ), time ( $p = .49$ ), or trial ( $p = .38$ ) effects. The mean difference (95% CI) in dribbling speed between CHO-E and placebo trials was  $0.03 [-0.24, 0.09] \text{ m}\cdot\text{s}^{-1}$ , with an effect size (Cohen's *d*) of 0.2 (small effect). Likewise, dribbling accuracy did not change over time in either CHO-E or placebo trials (Figure 2b) and was no time ( $p = .54$ ), trial ( $p = .41$ ), or Time  $\times$  Trial interactions ( $p = .38$ ). The mean difference (95% CI) in dribbling accuracy between trials was  $-0.03 [-0.23, 0.16] \text{ m}$ , with an effect size (Cohen's *d*) of 0.1 (trivial effect).

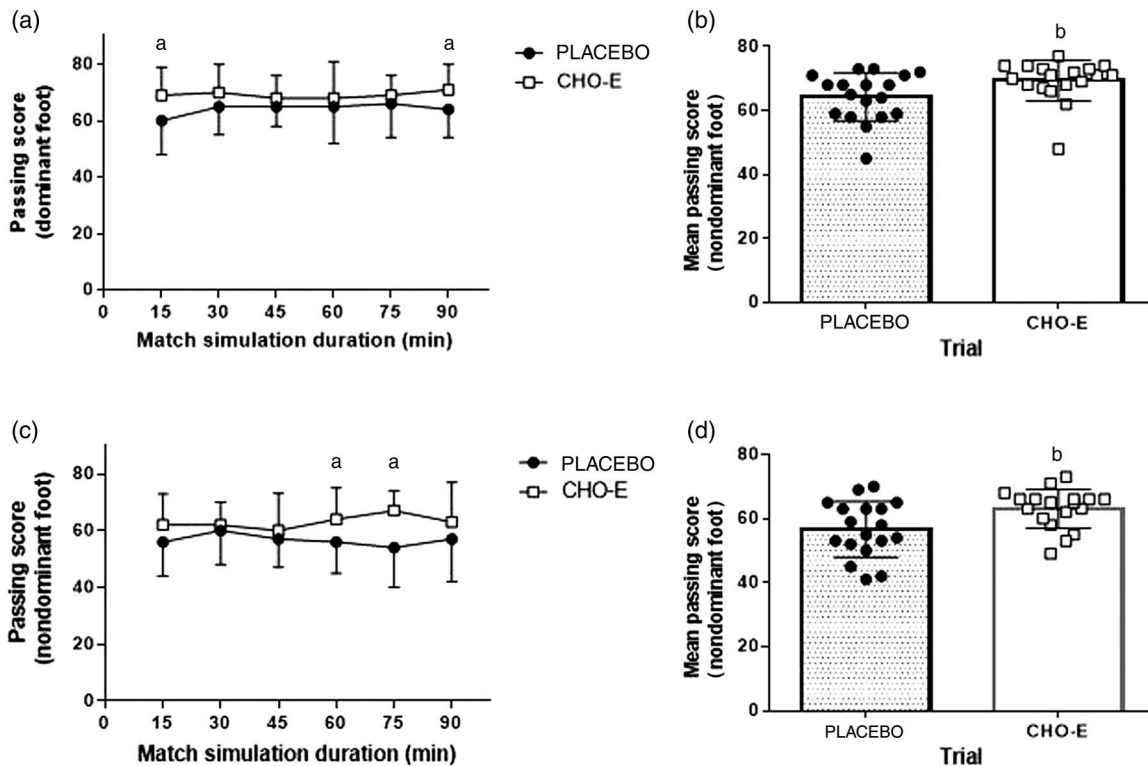
## Passing Accuracy and Speed

There was a significant Time  $\times$  Trial interaction ( $p = .02$ ) on passing score (accuracy) for both feet. Passing accuracy was greater in CHO-E than placebo at 15 min ( $p = .005$ ) and 90-min ( $p = .02$ ) time points for the dominant foot (Figure 3a) and at 60-min ( $p = .012$ ) and 75-min time points ( $p = .001$ ) for the nondominant foot (Figure 3c). Passing accuracy, calculated as mean scores measured during the SMS, also was greater in CHO-E than placebo when passes were completed with either the dominant (Figure 3b) or nondominant (Figure 3d) foot. The mean difference (95% CI) in passing score for the dominant foot between CHO-E and placebo trials was 5 [1, 9] points, with an effect size (Cohen's *d*) of 0.7 (moderate effect). The mean difference (95% CI) in passing score for the nondominant foot between trials was 6 [3, 10] points, with an effect size (Cohen's *d*) of 0.8 (moderate effect).



**Figure 2** — Dribbling speed (a) and dribbling accuracy (b) during the SMS on placebo and CHO-E trials. No main effects of trial, time, or Trial  $\times$  Time interaction were observed. CHO-E = carbohydrate-electrolyte; SMS = soccer match simulation.





**Figure 3** — Passing score (a) during the SMS and mean passing score (b) for the dominant foot. Passing score (c) during the SMS and mean passing score (d) for the nondominant foot. Significant main effects of trial ( $p < .05$ ) and Trial  $\times$  Time ( $p < .05$ ) interaction were observed. <sup>a</sup>Time points at which significant differences were evident between placebo and CHO-E trials. <sup>b</sup>Significant difference in mean passing score. CHO-E = carbohydrate-electrolyte; SMS = soccer match simulation.

Passing speed was similar on both trials for the dominant foot with no time, trial, or Time  $\times$  Trial interaction effects observed (all  $ps > .05$ ) (Figure 4a). The mean difference (95% CI) in passing speed between trials for the dominant foot was 0.4 [−0.1, 0.9]  $\text{km}\cdot\text{hr}^{-1}$ , with an effect size (Cohen's  $d$ ) of 0.2 (trivial effect). By contrast, for the nondominant foot, a significant Time  $\times$  Trial interaction was observed ( $p = .032$ ). Post hoc analyses revealed that passing speed was better maintained from 75 min onwards in CHO-E trial compared with placebo ( $p = .001$ ; Figure 4c). Mean passing speed was greater in CHO-E than placebo for the nondominant foot only ( $p = .04$ ; Figures 4b and 4d). The mean difference (95% CI) in passing speed for the nondominant foot between trials was 0.6 [0.1, 1.2]  $\text{km}\cdot\text{hr}^{-1}$ . The effect size (Cohen's  $d$ ) was 0.4 (small effect).

### Sprint Speed

Sprint speeds did not decline throughout the SMS with no time ( $p = .38$ ), trial ( $p = .47$ ), or Time  $\times$  Trial interactions ( $p = .31$ ), detected. In addition, average sprint speed during the 90-min SMS was similar between trials. The mean difference (95% CI) in sprint speed between trials was 5.9 [5.8, 6.1]  $\text{km}\cdot\text{hr}^{-1}$ . The effect size (Cohen's  $d$ ) was 0.2 (small effect).

### High-Intensity Anaerobic Endurance Running Capacity

Anaerobic endurance capacity, expressed as running distance completed at 90% of the  $\text{VO}_2\text{max}$ , was 11.8% better on the

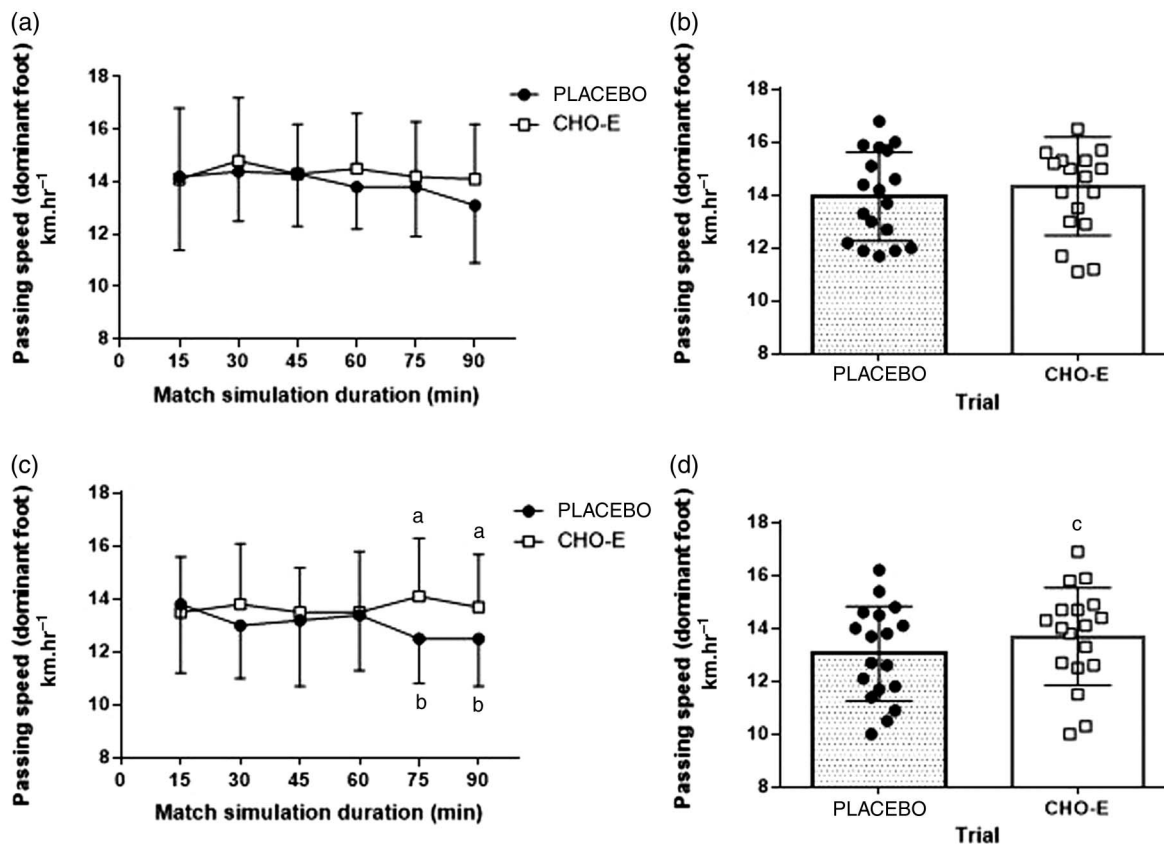
CHO-E trial than placebo ( $p = .01$ ; Figure 5). The mean difference (95% CI) in running capacity between trials was 54 [15, 94] m, with an effect size (Cohen's  $d$ ) of 0.4 (small to moderate effect).

### Gastrointestinal Comfort

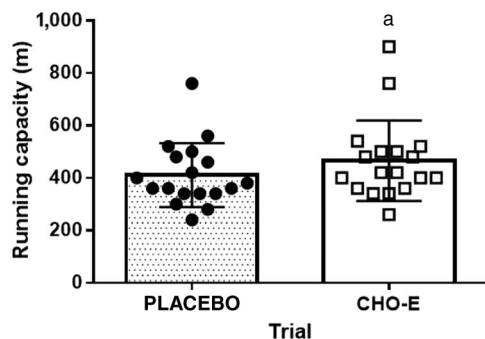
Visual analogue scale scores recorded for nausea were low and remained constant (15-min time point:  $12 \pm 15$  and 90-min time point:  $21 \pm 16$ ) throughout the SMS with no time ( $p = .536$ ), trial ( $p = .11$ ), or Time  $\times$  Trial ( $p = .37$ ) effects. There was a significant main effect of trial ( $p = .014$ ) and a Time  $\times$  Trial interaction for fullness ( $p = .007$ ), with participants reporting greater fullness scores in the CHO-E condition pretrial ( $39 \pm 22$ ) and at the end (90 min) of the SMS protocol ( $37 \pm 25$ ). Perceived feelings of bloatedness increased during the SMS, with participants feeling more bloated after ingesting the second drink at half time ( $45 \pm 23$ ), compared with pretrial feelings ( $30 \pm 22$ ), on both trials. However, there was no Time  $\times$  Trial ( $p = .78$ ) interaction for bloatedness scores.

### Blood Analytes

There was a significant Time  $\times$  Trial interaction ( $p = .001$ ), main time effect ( $p = .001$ ), and main trial effect ( $p = .002$ ) for capillary blood glucose concentration. Whereas a 26% decline in glucose concentration from halftime to the first 15 min of the second half in the CHO-E condition was observed, glucose concentrations remained constant in placebo. Glucose concentrations were greater in CHO-E than placebo at halftime and after completing the high-intensity running capacity test (Figure 6a). No significant



**Figure 4** — Passing speed (a) during the SMS and mean passing speed (b) for the dominant foot. Passing speed (c) during the SMS and mean passing speed (d) for the nondominant foot. Significant main effects of trial ( $p < .05$ ) and Trial  $\times$  Time ( $p < .05$ ) interaction were observed on nondominant foot only. <sup>a</sup>Time points at which significant differences in passing speed were evident between placebo and CHO-E trials. <sup>b</sup>A significant decrease in passing speed compared with 15-min value on PLACEBO trial only. <sup>c</sup>Significant difference in mean passing speed. CHO-E = carbohydrate-electrolyte; SMS = soccer match simulation.



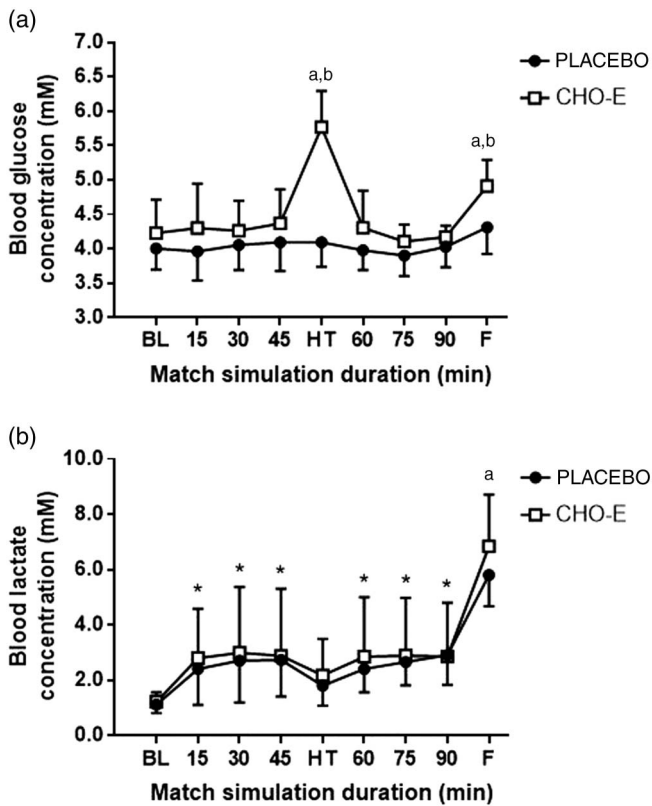
**Figure 5** — High-intensity anaerobic endurance running capacity on completion of the SMS on placebo and CHO-E drink ingestion trials. <sup>a</sup>Significant effect ( $p < .05$ ) with greater running capacity on CHO-E than placebo. CHO-E = carbohydrate-electrolyte; SMS = soccer match simulation.

Time  $\times$  Trial interaction effect ( $p = .12$ ) or main trial effect ( $p = .27$ ) was observed for blood lactate concentrations over the course of the SMS (Figure 6b). However, lactate values increased above baseline at 15 min and, with the exception of halftime, values remained constant during the 90-min SMS. Lactate concentrations increased after the high-intensity anaerobic endurance running capacity test.

## Discussion

The primary aim of this study was to investigate the influence of ingesting 60 g of carbohydrate as a 12% CHO-E solution, prior to and at halftime during a 90-min SMS, on soccer-specific skill performance, speed, and high-intensity running capacity in academy soccer players. The SMS protocol was performed on an indoor artificial grass surface 2 hr following intake of a prematch meal, compliant with the recommended carbohydrate guidelines. We demonstrated that ingesting the 12% CHO-E solution versus an electrolyte-matched placebo better maintained passing accuracy in both the early and latter stages of the SMS protocol and passing speed during the latter stages of the SMS protocol with minimal impact on gut comfort. Although there was no benefit of ingesting the 12% CHO-E solution on dribbling speed and accuracy, or sprint speed, compared with placebo, postmatch high-intensity running capacity was improved on the CHO-E trial. In terms of practical application, these data suggest that ingesting a 12% CHO-E solution before and during a soccer match may benefit soccer-specific skill performance and anaerobic endurance capacity.

A recent study reported the better maintenance of ball dribbling speed during the final 30 min of an SMS when ingesting a 12% CHO-E solution prematch and during halftime versus an electrolyte or water placebo condition (Harper et al., 2017). By contrast, we demonstrated no influence of ingesting a 12% CHO-E



**Figure 6** — Blood glucose (a), lactate (b) concentration during the SMS on placebo and CHO-E drink ingestion trials. <sup>a</sup>Significant difference ( $p < .05$ ) from zero time point. <sup>b</sup>Significant difference between trials at halftime and final time point. CHO-E = carbohydrate-electrolyte; SMS = soccer match simulation; BL = baseline; HT, halftime; F, final trial sample taken following running capacity test.

solution on dribbling speed versus an electrolyte-matched placebo. We speculate that this discrepant finding may be attributed to several methodological factors. Unlike previous studies, our experimental trials were performed on an artificial grass surface and players wore their own soccer boots, which may have facilitated the better execution of skills. Moreover, we chose to perform the trials in the early afternoon instead of the morning with the aim to better reflect competitive practices of this group of players in Scotland. In accordance with published carbohydrate recommendations for exercise (Thomas et al., 2016; Williams & Rollo, 2015), we also provided a standardized breakfast containing 46 g of carbohydrate in addition to a prematch meal consisting of 2 g carbohydrate per kg of body mass ingested 2 hr prior to starting the SMS protocol. By contrast, Harper et al. (2017) provided soccer players with a breakfast containing 10% of daily energy requirement (~35 g of carbohydrate) ingested ~135 min before exercise. Interestingly, whereas Harper et al. (2017) reported a statistically significant decline in dribbling speed over time, in this study, dribbling speed remained constant throughout the 90-min SMS protocol. Although muscle glycogen concentration was not measured in this study, we speculate that including a carbohydrate-rich prematch meal prevented the decline in muscle glycogen content that has previously been associated with impaired performance (Mohr et al., 2005). Hence, the benefit of ingesting a 12% CHO-E solution on ball dribbling performance appears to be context specific, for example, when it is not possible to comply with prematch

carbohydrate intake guidelines, and/or only when fatigue has a markedly detrimental impact on dribbling performance.

In this study, whereas ingesting the 12% CHO-E solution resulted in the better maintenance of passing accuracy in both dominant and nondominant feet, passing speed was better maintained with carbohydrate ingestion during the latter stages of the SMS protocol in the nondominant foot only. To our knowledge, this is the first study to differentiate between dominant and nondominant feet when measuring soccer passing performance. Previous work demonstrates that if a task is familiar to an individual, then there will be an element of automaticity, and fewer CNS resources are required for optimal performance (McMorris & Graydon, 1997). Conversely, when a task becomes more complex, the task outcome is more likely to be influenced by arousal (McMorris & Graydon, 1997). Thus, it is intuitive that performing the passing test with the nondominant foot required a greater allocation of CNS resources than when performing the passing test with the dominant foot. It also has been proposed that fatigue is associated with a decrement in central control (Welsh et al., 2002), thus it can be inferred that the nondominant side would demand more activity from the CNS, and therefore, be more susceptible to fatigue. Previous work has demonstrated that carbohydrate ingestion enhances CNS activity and motor control (Liu et al., 2000; Welsh et al., 2002). In this regard, Bottoms et al. (2007) showed that when compared with placebo the ingestion of a carbohydrate solution resulted in skill retention, specifically in the backhand drive (weaker shot) in squash players. Therefore, it is intuitive that ingesting the 12% CHO-E solution had a more profound effect on passing performance with the nondominant foot than with the dominant foot. Consistent with this proposed mechanism, it appears from our data that the impact of carbohydrate feeding is observed primarily with the nondominant foot, particularly toward the end of the SMS.

Studies showing a deterioration in soccer-specific skills (Ali & Williams, 2009; Ali et al., 2007; Ostojic & Mazic, 2002) when players did not consume carbohydrates have argued that lowered glucose concentrations are associated with declines in skill performance. In this study, blood glucose concentrations at halftime and at the end of the full protocol were significantly higher when ingesting the 12% CHO-E solution versus placebo. However, ingesting the 12% CHO-E solution failed to prevent the decline in blood glucose concentration 15 min into the second half of the SMS, likely reflecting increased glucose disposal at the onset of the second half of the SMS. Other studies (Russell et al., 2012) have reported skill performance decline in placebo condition versus carbohydrate consumption despite mean blood glucose concentration remaining euglycemic. Altogether, it appears that blood glucose concentration per se is not a key driver for the changes in skill performance detected between trials.

Blood lactate concentration during the SMS protocol was similar on both trials and reflects typical match intensity responses (Krustrup et al., 2006). Although marginal, the higher lactate concentrations in the CHO-E trial following the high-intensity anaerobic running test likely reflects greater capacity for flux through glycolysis in the face of additional substrate availability on that trial. Although sprint speed over 15 m did not decline throughout the SMS, mean values were comparable with those reported during actual match play (Krustrup et al., 2006). Interestingly, Balsom et al. (1992) previously demonstrated that 15-m sprints could be performed at 30 s intervals without impaired performance in the absence of carbohydrate supplementation. In this study, 18 × 15-m sprints were performed over the 90-min SMS



protocol separated by a minimum period of 5 min, during which lower intensity exercise intervals were performed. This protocol would suggest that there was sufficient time for phosphocreatine resynthesis between sprints, thus preventing a decline in sprint speed over the SMS on both trials. We reported that high-intensity running capacity following the SMS was significantly better in the 12% CHO-E versus placebo trial. Similar results were reported by Alghannam (2011) and Nicholas et al. (1995), supporting the argument that carbohydrate ingestion exhibits an ergogenic benefit on anaerobic endurance capacity after prolonged intermittent exercise.

In conclusion, ingesting a 12% CHO-E solution before an SMS protocol and at halftime aided the retention of soccer-specific skill performance, particularly passing performance toward the end of the SMS protocol and enhanced high-intensity running capacity after simulated match play. Soccer players typically experience fatigue toward the end of the match (Bradley et al., 2009; Mohr et al., 2005), and the number of goals conceded increases during the latter stages of the game (Reilly, 1997). This study adds to the evidence base that optimization of carbohydrate ingestion strategies appears to have a practically relevant benefit on key skill (passing) and physiological-related (high-intensity running capacity) factors that likely influence performance toward the end of a soccer match.

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