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Carbohydrate-Electrolyte Drink Ingestion and Skill Performance During and After 2 hr of Indoor Tennis Match Play

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Twenty-two tennis players were individually studied on 2 occasions. They performed a prematch skill test, a 2-hr tennis match against an equally ranked opponent, and a postmatch skill test. A carbohydrate-electrolyte (CHO-E; Lucozade Sport) or flavor-matched placebo-electrolyte (PL) beverage was administered in a double-blind fashion. During the trials, heart-rate and movement intensity were monitored, and the match was recorded for performance analysis. There were no differences in skill-test scores pre- to postmatch or between trials (154 ± 38 pre- and 160 ± 35 postmatch on PL, 155 ± 36 pre- and 165 ± 33 postmatch on CHO-E). CHO-E ingestion elevated blood glucose concentration throughout the match, and participants reported feeling more energetic (general activation) and more tense (high activation) 1 hr into the match than at baseline ($p < .05$). Participants in the CHO-E trial spent more time in moderate-intensity activity and less time in low-intensity activity than on PL. Performance analysis revealed that CHO-E ingestion increased overall serve success ($M \pm SD$, 68% ± 7% for CHO-E vs. 66% ± 7% for PL; $p < .05$) and success of first serves (65% ± 9% for CHO-E, 61% ± 7% for PL; $p < .01$) and serves to the advantage side (70% ± 9% for CHO-E, 66% ± 7% for PL; $p < .05$). Return success was greater during the second set of the match ($p < .05$) in the CHO-E trial. Differences in serve and return success were not associated with blood glucose response to CHO or player ability.

Keywords: fatigue, notational analysis, sport drink

The beneficial effects of carbohydrate (CHO) ingestion on endurance-exercise capacity and performance and intermittent-exercise performance have been well documented (Coyle et al., 1983; Nicholas, Williams, Lakomy, Phillips, & Nowitz, 1995; Roberts et al., 2010). Fasting, exercising for a prolonged period of time, and exercising at a high intensity can all induce fatigue, which in turn has been demonstrated to negatively influence skill performance (Davey, Thorpe, & Williams, 2002; McGregor, Nicholas, Lakomy, & Williams, 1999; Vergauwen, Brouns, & Hespel, 1998). Studies examining the effects of CHO ingestion on skill performance in a range of sports have produced mixed findings to date, with some illustrating no beneficial effects (Mitchell, Cole, Grandjean, & Sobczak, 1992; Zeederberg, Lambert, Noakes, Dennis, & Hawley, 1996) and others providing some evidence of maintained skill performance (Ali & Williams, 2009; Bottoms, Hunter, & Galloway, 2006; Vergauwen et al., 1998).

Typically, studies that have observed maintained skill performance after CHO ingestion have either induced fatigue beyond that normally experienced in a real match situation, included an overnight fast, or incorporated glycogen-depleting exercise before testing (e.g., Ali, Williams, Nicholas, & Foskett, 2007; Davey et al., 2002; Davey, Thorpe, & Williams, 2003; Winnick et al., 2005). Therefore, our understanding of the impact of CHO feeding on skill retention in real-world "fed" situations is at best incomplete. Furthermore, it is evident that little attention has been paid to the effects of CHO feeding on skill performance throughout competitive match situations. It is therefore important to identify the potential effects of CHO feeding on skill performance using more ecologically valid approaches that can provide practical guidance for athletes.

The aim of the current study was to examine the effect of CHO-electrolyte (CHO-E) drink ingestion compared with placebo on skill and key match-performance measures in tennis players. We hypothesized that 2 hr of tennis match play would induce sufficient fatigue to reduce skill and match performance and that CHO-E drink ingestion would help maintain skill compared with ingestion of a placebo-electrolyte beverage.

Methods

Twenty-two nationally ranked tennis players (15 male, 7 female; M [SD] height 177.1 [7.7] cm, weight 69.2 [9.5] kg, age 22.0 [7.3] years, maximum heart rate 189 [8] beats/min; sum of four skinfolds 41.6 [16.5] mm) came to the laboratory on four separate occasions over a period of 3–4 weeks. The study was approved by a formally constituted ethics review board, and informed consent was obtained in writing from participants (or guardians

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for participants under the age of 18 years). The first visit was for prescreening followed by a graded maximal treadmill test to exhaustion to determine individual heart-rate-intensity relationships. The second visit was a practice trial in which participants were taken through all the testing procedures of the two main trials. These first two visits were conducted a few days apart and 1 week before the first main trial.

The final two visits were the main trials and were conducted 1 or 2 weeks apart and at the same time of day. For every trial, only 1 participant was tested at any one time. Participants' opponents were only involved for the purpose of the matches. Dietary intake and physical activity were recorded by participants for 3 days preceding the first main trial and replicated in the 3 days preceding the second main trial. No strenuous exercise was performed on the day preceding each of the main trials.

Participants came to the laboratory 3 hr after ingesting a self-standardized breakfast (consisting of cereal with milk, orange juice, and toast with jam). On arrival, nude body mass, urine and blood samples, and subjective measures of feeling (Hardy & Rejeski, 1989), arousal (Svebak & Murgatroyd, 1985), and activation (Activation-Deactivation Adjective Checklist [AD-ACL]; Thayer, 1989) were obtained. Participants were then instrumented with a heart-rate monitor (Polar S625×, Polar, Finland) and accelerometer (Actigraph GT1M, USA) to enable monitoring of playing and movement intensity before going to the indoor tennis court. On court, they performed a 10-min standardized warm-up (consisting of 5 min of specific dynamic warm-up drills and 5 min of groundstroke warm-up starting from the service line and gradually moving back to the baseline). The warm-up was followed by a prematch skill test. After a further 5-min match warm-up (groundstrokes, serves, and volleys) participants played a 2-hr tennis match against an opponent of similar playing ability (based on Lawn Tennis Association and coach rankings). Matches were played with the participant ingesting either a 6.4% CHO-E drink (Lucozade Sport, GlaxoSmithKline Nutritional Healthcare, 281 mOsmol/kg) or a 0.0% placebo-electrolyte beverage (Lucozade Sport, GlaxoSmithKline Nutritional Healthcare, 61 mOsmol/kg). Drinks were administered as a bolus volume (5ml/kg) after the initial skill test and subsequent volumes (3 ml/kg) every 20 min. They were supplied and labeled by the manufacturer and were administered by the researcher in a double-blind, placebo-controlled, random-stratified crossover design. All drinks were kept cool (10 °C) during the trials. Immediately on completion of the 2-hr match the participants performed a postmatch skill test.

After the postmatch skill test a final nude body mass was recorded. All matches were recorded using a wall-mounted camera at the rear of the court for later performance analysis. Temperature and humidity of the tennis court were recorded before and during testing using a digital barometer (Cranlea, Birmingham). The overall schedule for each main trial is presented in Figure 1.

Skill-Test Protocol

Participants were assessed on the accuracy of groundstrokes and the accuracy and speed of serve in an unopposed playing situation, using a protocol modified from Davey et al. (2002). Participants performed 22 alternate crosscourt and down-the-line forehand drives, aiming at a target (3 m^2) placed in the back corner of the court (Figure 2), using Tretorn Micro X tennis balls fed to the player by a ball-feeding machine (Lobster Elite 3, Grimshaw Group, Gloucestershire, UK). The first two balls from each 22 were excluded from scoring. The test was replicated on the backhand side, with alternate crosscourt and down-the-line backhand drives. This was then repeated again, giving a total of 40 forehand and 40 backhand drives. Groundstroke test score was recorded using a 4-point scoring system (Figure 2). After a 2-min service warm-up participants then completed a serving

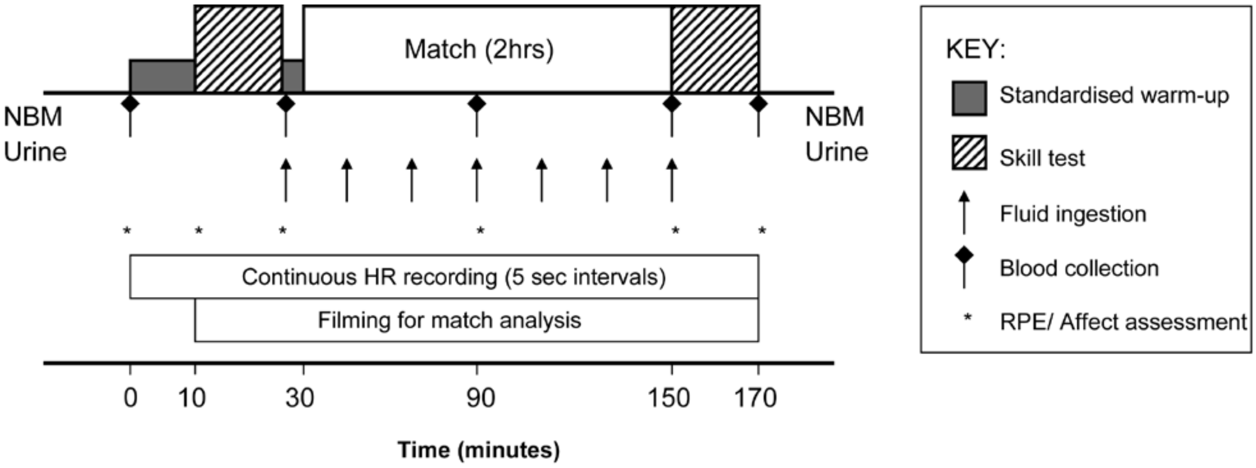

Figure 1 — Diagram showing sequence of events during the two main trials. NBM = nude body mass; HR = heart rate; RPE = rating of perceived exertion.

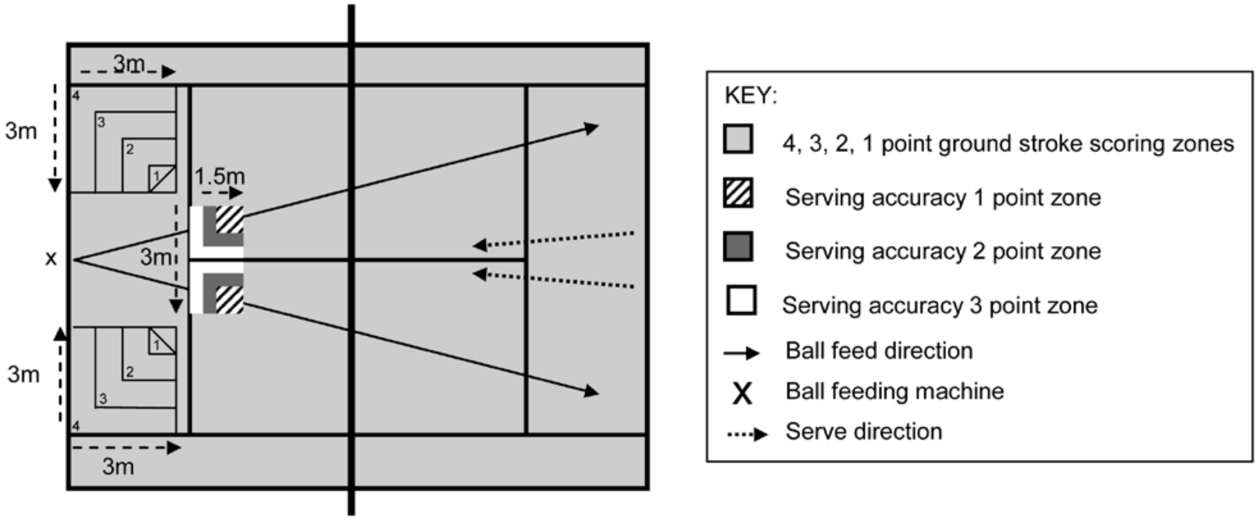

Figure 2 — Skill-test zones for accuracy and consistency of groundstrokes and serves. Modified version of that reported by Davey et al. (2002).

skill test involving 10 first serves to the deuce court, 10 first serves to the advantage court, and 10 second serves to each service side (40 serves in total). Groundstrokes and serves landing in court but outside the scoring zones scored zero, while balls out of court or in the net were recorded as errors. Speed of service (km/hr) was recorded using a Sports Radar gun (SR3600, Sports Radar Ltd., Derbyshire, UK) positioned behind the ball machine in the center of the court.

Heart-Rate and Movement Intensity

Heart rate was monitored continuously during the skill tests and match play in both trials for the participant and the opponent. Heart-rate-intensity zones for the participants during the match were defined as low intensity (<60% max), moderate intensity (60–85% max), and high intensity (>85% max), with the individual maximum heart rate determined from the baseline incremental treadmill running test. Accelerometry data were classified into intensity zones (light, moderate, and vigorous) according to the cutoff points of Ekelund et al. (2006).

Performance Analysis

During the match, Tretorn Serie+ tennis balls were used, with new balls provided after 1 hr of play. Camera footage was used to track performance variables using Focus X2 software (Elite Sports Analysis, Scotland, UK). Key variables extracted for use in this study included number of serves, serve outcome, serve outcome by side (deuce serves/advantage serves), serve outcome by serve (1st serve/2nd serve), number of returns of serve, return outcome, return outcome by side (deuce/advantage), number of rallies, rally outcome (point won/lost), forced errors, and unforced errors.

Fluid-Loss and Urine Analysis

Pre- and postmatch urine total volume was recorded for correction of body-mass change to estimate sweat loss. A sample of urine was retained for measurement of urine osmolality (freezing-point-depression method, Roebling). Any fluid lost through respiratory or substrate exchange was disregarded because of the likely small effect when calculating sweat loss.

Blood Analysis

All blood samples were obtained by capillary sampling, and duplicate 20-µl aliquots were dispensed into 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 –80 °C until subsequent analysis for blood glucose and lactate, using the glucose-oxidase method (ABX diagnostics) and the method of Maughan (1982), respectively.

Statistical Analyses

Primary outcomes (skill-test scores and match-performance-analysis variables) and secondary outcomes (subjective measures of performance including affect, rating of perceived exertion [RPE], and blood and urine parameters) were analyzed for baseline score differences using one-way analysis of variance (ANOVA). Analysis between baseline and the end of the trial was performed using a repeated-measures ANOVA (RMANOVA) with post hoc Tukey tests, with time and trial as the main within-group factors. Performance-analysis data were compared between placebo and CHO-E treatment trials using RMANOVA and paired *t* tests where appropriate. Correlation analysis was also performed to examine any associations between change in skill performance (serve and return success) and blood glucose elevation (change from predrink to peak concentration) and player ability (based on initial skill-test score). Analysis was performed using Minitab version 15, and significance was accepted at $p < .05$. All data are expressed as *M* (*SD*).

Results

Each match was played indoors on a hard-court surface. Mean ± *SD* court temperature and relative humidity for the CHO-E trials were 21.3 ± 1.1 °C and 37.1% ± 4.5%, respectively, and 21.8 ± 2.1 °C and 35.4% ± 3.1% for the placebo trials, with no difference between trials. There were no differences between trials for baseline urine osmolality (639 ± 296 and 687 ± 284 mOsmol/kg), baseline body mass (69.0 ± 9.3 kg and 69.2 ± 9.3 kg), loss in body mass (0.6 ± 0.5 kg and 0.6 ± 0.6 kg), and sweat rate (0.8 ± 0.2 and 0.8 ± 0.2 L/hr) for placebo and CHO-E trials, respectively. On completion of all trials participants were asked to identify the trial in which they had consumed the CHO-E beverage, and only 50% guessed correctly.

Skill-Test Data

There were no differences between the CHO-E and placebo trials for total skill-test score (groundstroke and serve scores combined), groundstroke total score, or serve total score (Figure 3). In addition, there was no decline in skill-test score pre- to postmatch for the placebo or CHO-E trials. No differences between trials were noted when scores were broken down by scoring zone or for speed of serve (data not shown). Participants' heart rates during the pre- and postmatch skill tests were 137 ± 18 and 132 ± 18 beats/min, respectively, for placebo and 139 ± 20 and 135 ± 14 beats/min for CHO-E.

Performance-Analysis Data

Analysis of performance during the 2-hr match revealed that participants in the CHO-E trial had significantly higher success rates on all serves ($p < .05$; 66% ± 7% success on placebo vs. 68% ± 6% on CHO-E). More notably, in the CHO-E trial success on first serves ($p < .01$) and advantage serves ($p < .05$) was greater than on placebo (65% ± 7% vs. 61% ± 7% for first serves and 70% ± 8% vs. 66% ± 7% for advantage serves on CHO-E and placebo, respectively; Figure 4). However, when the service data were broken down by set there were no set (time) differences observed, and improved service success did not translate to more points won when serving.

Further analysis revealed that return of serve from the deuce side in the CHO-E trial tended to be more successful ($p = .08$) than in the placebo trial (Figure 4). Participants on the CHO-E drink successfully returned 50% ± 9%, compared with 46% ± 10% in the placebo trial. Participants in the CHO-E trial also returned more serves successfully ($p < .05$) during the second set of the match (51% ± 12% vs. 44% ± 12% success on returns for CHO-E and placebo trials, respectively; Figure 4). However, improved return success did not translate to winning more total points when returning.

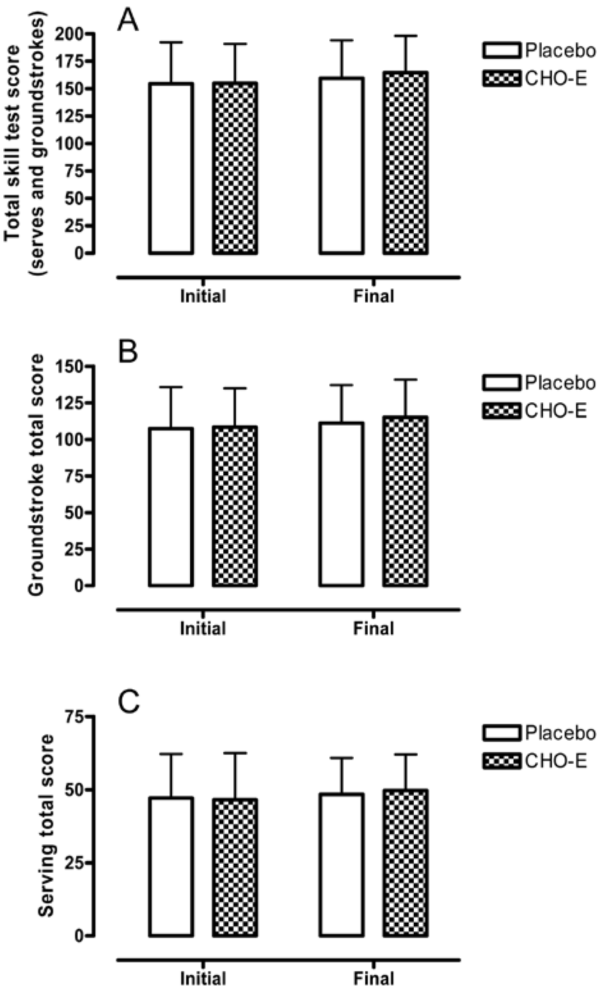

Figure 3 — (A) Skill-test total score, (B) groundstroke total score, and (C) serving total score before and after 2 hr of tennis match play with ingestion of placebo or carbohydrate-electrolyte (CHO-E) drink, *M* (*SD*).

There were no differences between the placebo and CHO-E trials for total number of rallies in the match (117 ± 21 on placebo and 123 ± 22 on CHO-E), shots per rally (3.6 ± 0.7 on placebo and 3.6 ± 0.7 on CHO-E), or total number of rallies by set. Similarly, there was no difference in the number of unforced errors, either for total unforced errors throughout the whole match (51 ± 23 on placebo and 51 ± 24 on CHO-E) or number of unforced errors by set.

Metabolite and Match-Intensity Data

There were trial, time, and Trial × Time effects on blood glucose after CHO-E ingestion ($p < .01$; Figure 5).

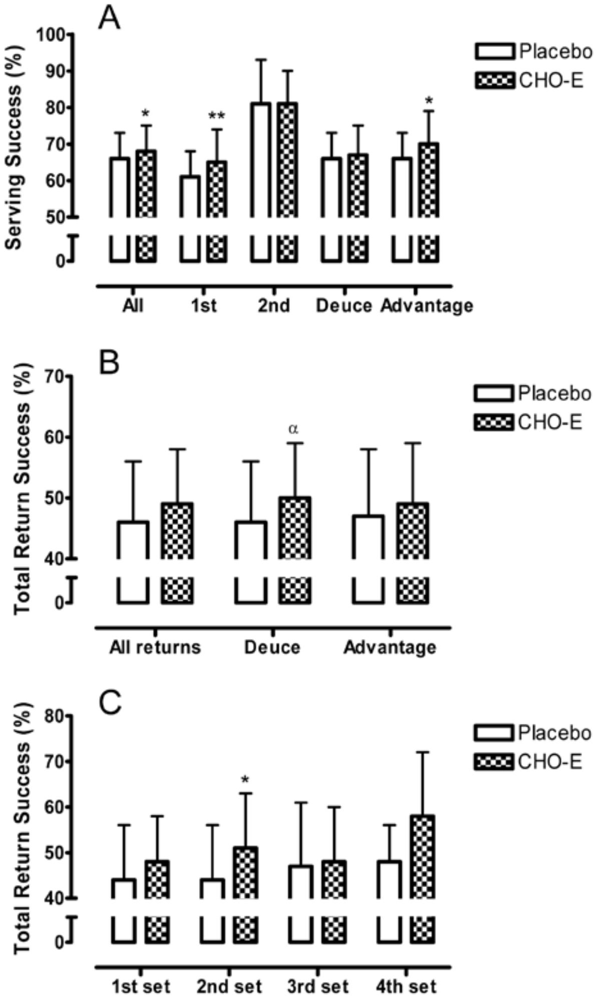

Figure 4 — (A) Service success recorded during 2 hr of tennis match play for all serves (All), first serves (1st), second serves (2nd), serves to the deuce side (Deuce) and serves to the advantage side (Advantage); (B) percentage of total returns that were successful for all returns, returns from the deuce side, and returns from the advantage side; and (C) percentage of total returns that were successful when broken down by set, on trials with ingestion of placebo or carbohydrate-electrolyte (CHO-E) drink, *M* (*SD*). $^{\alpha}$Trend for an effect ($p = .08$). *Significant difference between trials ($p < .05$).

However, no differences were observed for blood lactate response between trials at any of the sample times, and mean blood lactate concentration remained low throughout both trials (1.75 ± 0.50 mmol/L on placebo and 1.77 ± 0.64 mmol/L on CHO-E; Figure 5).

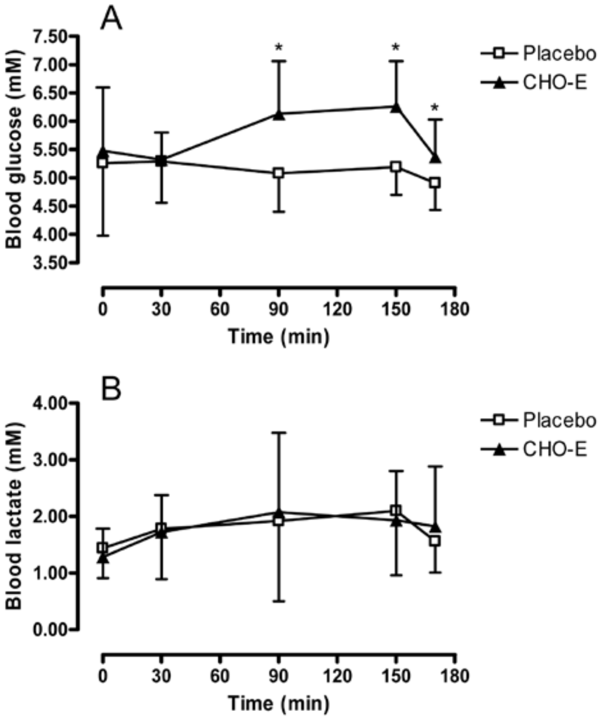

Figure 5 — (A) Blood glucose and (B) blood lactate concentration before, during, and after 2 hr of tennis match play with ingestion of placebo or carbohydrate-electrolyte (CHO-E) drink, *M* (*SD*).

No differences were identified between trials for the participants' or opponents' heart rate during the first and second hours of the match. Mean ± *SD* heart rates for the participants in the placebo trial were 131 ± 19 and 127 ± 18 beats/min for the first and second hours of match play, respectively, and in the CHO-E trial were 135 ± 20 and 130 ± 18 beats/min for the first and second hours of match play, respectively. For the opponents, heart rates in placebo trials were 132 ± 19 and 127 ± 20 beats/min for the first and second hours, respectively, and in CHO-E trials were 132 ± 21 and 130 ± 21 beats/min for first and second hours, respectively. Accelerometry indicated that the participants spent less time in low-intensity activity and more time in moderate-intensity activity during the CHO-E trial ($p < .05$; Figure 6). Heart-rate-intensity-zone data showed a similar pattern but did not reach statistical significance (Figure 6).

Subjective Measures

A significant Time × Trial interaction ($p < .05$) was observed for energetic and tense ratings on the AD-ACL. Post hoc analysis revealed higher energetic (general activation) and tense (high activation) ratings 1 hr into the match than at baseline in the CHO-E trial only (i.e., at 90 min into the test protocol; Table 1). An increase in RPE over time ($p < .05$) was observed for both trials, with no difference between trials. Mean RPEs during match play were 13.5 ± 1.6 (range 9–17) and 13.8 ± 1.9 (range 8–18) during the placebo and CHO-E trials, respectively. During the final skill tests, RPEs were 14.2 ± 1.9 (range 11–19) and 13.6 ± 1.7 (range 11–17) for placebo and CHO-E trials, respectively. No other main effects were identified in the AD-ACL, feeling, or arousal scales.

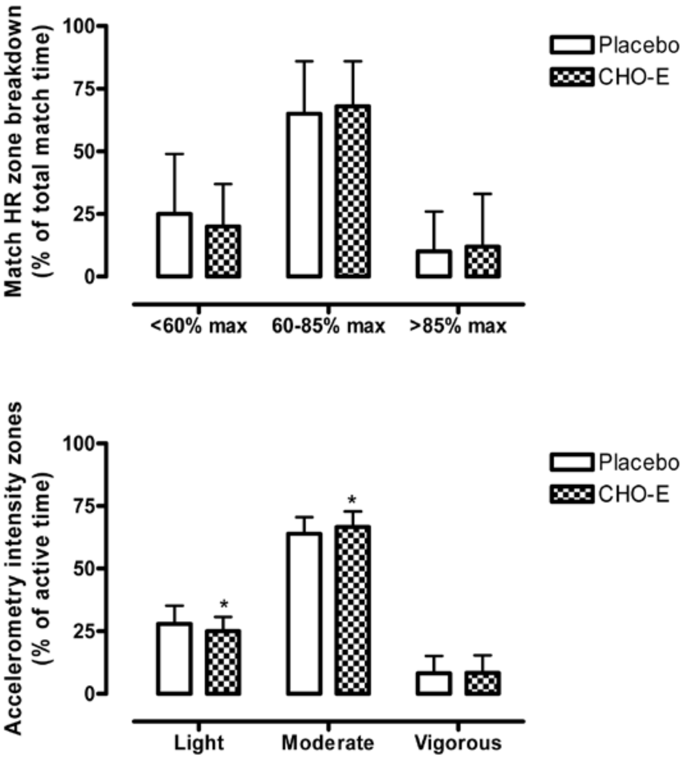

Figure 6 — Breakdown of (top panel) participant heart rate (HR) by zone and (bottom panel) accelerometry-intensity zones during 2 hr of tennis match play, with ingestion of placebo or carbohydrate-electrolyte (CHO-E) drink, *M* (*SD*). *Significant difference between trials ($p < .05$).

Associations Between Variables

Change in blood glucose response to feeding was not associated with change in first-serve ($r = .14$, $p = .54$) or advantage-serve success ($r = .02$, $p = .94$). When players were ranked based on placebo-trial serving success, no association was found with the subsequent change in first-serve success ($r = .13$, $p = .57$) or advantage-serve success ($r = .18$, $p = .43$) after CHO-E ingestion.

Discussion

The study found that a 2-hr tennis match did not induce sufficient fatigue to influence skill-test performance, and CHO-E drink ingestion did not influence unopposed skill-test scoring ability. However, CHO-E drink ingestion increased overall percentage of successful serves and improved return-of-serve success during match play. CHO-E drink ingestion also increased perceived activation 1 hr into the match and increased intensity of movement sustained on court compared with placebo.

Skill-Test Outcomes

No difference was observed between the CHO-E and placebo trials or between the pre- and postmatch skill-test scoring on any aspect studied (serve and groundstroke accuracy and speed of serve). The skill-test data indicate that after a 2-hr competitive tennis match, players' ability to maintain speed and accuracy of shots was not impaired. It is noteworthy that the participants' heart-rate responses during the skill tests were not significantly different between trials, indicating that they were able to maintain a similar intensity of effort in both trials before and after a 2-hr period of tennis match play. It should also be emphasized that the heart-rate and RPE responses during the skill tests closely matched those obtained during the match-play situation.

Previous studies that observed decrements in skill performance after exercise elicited higher levels of exertion in the skill tests than would normally be seen in a real match situation and often incorporated exercise to fatigue rather than a real match element between the pre- and postexercise skill assessments (e.g., Bottoms et al., 2006; Davey et al., 2002). For example, Davey et al. (2002) used short high-intensity tests to elicit volitional fatigue in their participants. Players subsequently reported peak RPE scores of 20 ± 0 from as early as 75% into the intermittent test, along with a peak blood lactate concentration of 9.6 ± 0.9 mmol/L recorded 25% into the intermittent test, both much higher than we observed in the current study during tennis match play.

If we presume that CHO-E drink ingestion is only likely to maintain skill performance when players are

Table 1 Psychological Responses Throughout the Trials With Ingestion of Placebo or Carbohydrate-Electrolyte (CHO-E) Drink, *M* (*SD*)

	Time (min)					
Psychological measure	**0**	**10**	**30**	**90**	**150**	**170**
Feeling Scale						
Placebo	1.2 (2.3)	1.7 (1.8)	1.6 (1.7)	1.4 (2.2)	1.2 (2.2)	0.5 (2.4)
CHO-E	1.0 (2.3)	1.7 (2.1)	0.9 (2.1)	1.4 (2.3)	1.5 (2.4)	1.1 (1.7)
Felt Arousal						
Placebo	2.6 (1.0)	3.4 (0.8)	3.5 (1.0)	3.4 (1.3)	3.0 (1.3)	2.6 (0.9)
CHO-E	2.4 (1.0)	3.3 (1.0)	3.3 (0.9)	3.5 (0.8)	3.1 (1.2)	2.9 (0.9)
Activation–Deactivation Adjective Checklist						
Energetic						
placebo	2.1 (0.6)	2.7 (0.6)	2.6 (0.6)	2.6 (0.9)	2.3 (0.9)	2.1 (0.8)
CHO-E	1.9 (0.7)	2.6 (0.8)	2.6 (0.8)	2.8 (0.7)*	2.4 (0.8)	2.3 (0.7)
Calm						
placebo	2.3 (0.6)	1.7 (0.4)	1.6 (0.5)	1.7 (0.5)	1.9 (0.6)	2.0 (0.7)
CHO-E	2.4 (0.6)	1.8 (0.5)	1.7 (0.5)	1.7 (0.6)	1.7 (0.6)	1.9 (0.6)
Tired						
placebo	2.3 (0.9)	1.8 (0.7)	1.7 (0.8)	1.7 (0.6)	2.0 (0.7)	2.2 (0.8)
CHO-E	2.3 (0.9)	1.8 (0.7)	1.8 (0.8)	1.8 (0.7)	1.9 (0.7)	1.9 (0.7)
Tense						
placebo	1.2 (0.3)	1.4 (0.5)	1.4 (0.3)	1.5 (0.5)	1.4 (0.5)	1.3 (0.3)
CHO-E	1.2 (0.3)	1.4 (0.5)	1.6 (0.5)	1.7 (0.6)*	1.6 (0.5)	1.4 (0.4)
Rating of Perceived Exertion						
Placebo	—	10.7 (1.4)	13.0 (1.6)†	13.2 (1.5)†	13.9 (1.8)†	14.2 (2.0)†
CHO-E	—	10.4 (1.8)	13.1 (1.7)†	13.6 (1.8)†	14.0 (2.3)†	13.6 (1.7)†

*Significant difference ($p < .05$) from 0 time point within that trial. †Significant difference ($p < .05$) from 10-min time point within that trial.

fatigued, rather than enhance it in a nonfatigued situation, it may not be surprising that unopposed skill-test performance did not differ between placebo and CHO-E drink ingestion in the current study. We can, therefore, conclude that 2 hr of tennis match play did not induce sufficient fatigue to affect this type of unopposed skill-assessment task.

Performance Analysis of the Match

A higher serving success during the match, more specifically first serves and advantage serves, in the CHO-E trial indicates that CHO can affect key match skills in an opposed playing situation even in the absence of fatigue. The lack of difference in serving success between trials across individual sets indicates that the increase in serving success was cumulative throughout the match, rather than occurring at any one point in time. An explanation for this effect is difficult to determine from the current data because there was no association between the change in blood glucose response to feeding and the change in first-serve or advantage-serve percentage in the CHO-E trial. There was also no association with the size of the effect and player ranking and ability. This suggests that neither the magnitude of elevation in blood glucose concentration nor the skill or ability level of the player influenced the outcome, per se. Further work examining the effects of CHO-E drink ingestion on service success is needed to identify the possible reasons for improved success.

We previously suggested (Bottoms et al., 2006) that an elevation in blood glucose concentration per se may explain maintenance of skill with CHO ingestion during fatiguing exercise. However, the lack of association between glucose elevation and change in skill performance in the current study suggests that central neural effects of CHO-E drink ingestion are a more likely explanation. Oral sensing of CHO (Chambers, Bridge, & Jones, 2009) and influences of CHO on visual-reaction time (Bottoms et al.,

2006) are likely to influence movement and performance in sports such as tennis, but this requires further investigation. Indeed, complex tasks or weaker shots that require high levels of central nervous system activation (McMorris & Graydon, 1997) are more likely to be influenced by CHO-E ingestion (as observed by Bottoms et al., 2006). It is also possible that activities carried out at a higher speed are more sensitive to the effects of CHO (Welsh, Davis, Burke, & Williams, 2002). In addition, during competitive situations psychological stress is known to increase circulating blood glucose as a result of sympathetic activation (Kovacs, 2006). However, very high-stress situations have also been linked to breakdown of well-learned skills in experienced performers, leading to suboptimal performance (Beilock & Carr, 2001). Thus, it could be proposed that during tennis match play in which first serves and advantage serves are critical, because games are typically won or lost more often from the advantage side, the increased stress may be influenced by CHO-E ingestion to achieve an optimal arousal/activation level.

Because CHO ingestion has been shown to influence visual-reaction time (Bottoms et al., 2006), this could explain the significantly greater return success observed during the second set of the match. The timing of this observation also coincides with elevated perceived activation 1 hr into the match (during the second set) in the CHO-E trial. The enhanced perceived activation is consistent with previous reports of CHO-E drink ingestion during prolonged exercise (Backhouse, Ali, Biddle, & Williams, 2007), but there are no previous studies that observed improved shot outcomes in conjunction with higher perceived activation. Given that the average number of shots per rally in competitive hard-court tennis matches is 2–3 (Deutsch, Deutsch, & Douglas, 1988), and was 3.6 in the current study, it is clear that the serve and return both play dominant roles. Further research into the effects of CHO and reaction time (e.g., Bottoms et al., 2006; Owens & Benton, 1994) and anticipatory skill (e.g., Hornery, Farrow, Mujika, & Young, 2007a) on these shot outcomes during a real tennis match may provide possible explanations for the current findings.

Mean heart rate observed during the 2-hr matches was lower than reported in other studies (Fernandez-Fernandez, Mendez-Villanueva, Fernandez-Garcia, & Terrados, 2007; Hornery, Farrow, Mujika, & Young, 2007b). Participants in previous research without prescribed fluid ingestion and at higher ambient temperatures are likely to have experienced some degree of dehydration and cardiovascular drift (Noakes, 1993) that would explain the different observations. Although we did not record participants' core body temperature, the ambient temperature and humidity were not high. Furthermore, urine and body-mass analysis revealed that fluid ingestion during both trials was adequate to offset sweat losses and effectively maintain hydration status.

Accelerometry analysis revealed that participants spent less time in low-intensity activity and more time in moderate-intensity activity during the CHO-E trial than with placebo. This pattern of response was also observed in the heart-rate data. Whether there is a link between sustaining an increased intensity of activity and the higher levels of perceived activation noted in the CHO-E trial is difficult to determine.

Conclusions

The current observations provide some novel and interesting data on the role of CHO-E drink ingestion in skill sports. The data reveal that skill-test performance did not decline and is not influenced by CHO-E intake, suggesting that 2 hr of match play did not induce sufficient fatigue to affect skill. However, in situations of opposed match play a beneficial effect of CHO-E feeding can be observed in serve and return success, which are key aspects of tennis performance. Further work is required to investigate possible mechanisms for these observations.

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