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Abstract

This study investigated the influence of consuming a 2, 6, and 10% carbohydrate-electrolyte (CHO-E) solution on the intermittent endurance capacity and sprint performance of adolescent team games players. Seven participants (five males and two females; mean age 13.3 ± 0.5 years, height 1.71 ± 0.05 m, body mass (BM) 62.0 ± 6.3 kg) performed three trials separated by 3 to 7 days. In each trial, they completed four 15 min periods of part A of the Loughborough Intermittent Shuttle Test (LIST) followed by an intermittent run to exhaustion (part B). Participants consumed 5 $ml.kg^{-1}$ BM of the solution during the 5 min pre-exercise period, and a further 2 $ml.kg^{-1}$ BM every 15 min during part A of the LIST. Intermittent endurance capacity increased by 34% with ingestion of the 6% CHO-E solution compared with the 10% solution (5.5 ± 0.8 vs. 4.1 ± 1.5 min, $P < 0.05$), equating to a distance of 931 ± 172 vs. 706 ± 272 m ($P < 0.05$). There was no significant difference between the 2% (4.8 ± 1.2 min) and 6% ($P = 0.10$) or the 2% and 10% solutions ($P = 0.09$). Carbohydrate concentration did not significantly influence mean 15 m sprint time ($P = 0.38$). These results suggest that the carbohydrate concentration of an ingested solution influences the intermittent endurance capacity of adolescent team games players with a 6% solution significantly more effective than a 10% solution.

Key Words: Team games; performance; nutrition; young people; LIST

Introduction

We recently reported a significant 24% improvement in intermittent endurance running capacity (hereafter referred to as intermittent endurance capacity) when 12-14 year old team games athletes ingested a 6% carbohydrate-electrolyte (CHO-E) solution before and during a modified Loughborough Intermittent Shuttle Test (LIST, Phillips et al 2010). This was achieved using the same body mass (BM)-standardised ingestion volumes and timings as the original adult work of Nicholas et al (1995). The lack of a significant treatment effect on heart rate (HR), ratings of perceived exertion (RPE), sweat rate (SR) or BM loss in our previous study also mirrored the findings of most relevant adult studies (Ali et al 2007; Davis et al 1999; Nicholas et al 1995; Welsh et al 2002). This suggests that the relative physiological responses to intermittent endurance running with carbohydrate (CHO) supplementation appear similar between adolescents and adults.

Most previous adult studies that demonstrated improved intermittent endurance capacity with CHO ingestion during intermittent endurance running used a CHO concentration ([CHO]) of 6.0-6.9% (60-69 $g.L^{-1}$ of solution, Davis et al 1999; Nicholas et al 1995; Welsh et al 2002). This is similar to existing guidelines for CHO supplementation during prolonged steady-state exercise for adults, i.e. a recommendation of ~1.0-1.1 $g.min^{-1}$ (60-70 $g.h^{-1}$, Jeukendrup 2004) to maximise exogenous CHO (CHO_{exo}) oxidation. However, it cannot be assumed that these guidelines for steady-state exercise also apply to CHO ingestion during participation in team games. Christmass et al (1999) demonstrated a 1.2 times higher ($P < 0.05$) rate of endogenous CHO (CHO_{endo}) oxidation during 90 min of sustained intermittent compared with continuous running at the same overall $\dot{V}O_2$. This suggests that the requirement for CHO may be greater during intermittent compared with continuous exercise. Some studies have

investigated the influence of [CHO] on endurance capacity during prolonged intermittent exercise (Murray et al., 1987). However, protocol issues make drawing conclusions on the influence of [CHO] difficult, and also preclude the application of the findings to team games. To date, no published research has investigated the influence of consuming different [CHO] during intermittent endurance running. Ali and Williams (2009) reported no benefit of ingesting CHO at a rate of 52 $g.h^{-1}$ on sprint performance during the LIST, but did report a significant improvement in sprint performance with ingestion of 32 g $CHO.h^{-1}$ (Ali et al 2007). However, intermittent endurance capacity, where CHO ingestion most consistently exerts an effect during intermittent endurance running, was not assessed in these studies.

Due to a lack of empirical research, no published guidelines exist for CHO supplementation during team games exercise in adolescents. The findings of Phillips et al (2010) were generated despite one fewer drink period compared with adult work, as adolescents commonly play team games for a shorter duration than adults (60 min *vs*. 90 min, Ekblom 1986). As a result, mean CHO intake was 0.56 $g.min^{-1}$ compared with ~0.79-1.3 $g.min^{-1}$ in adult work (Nicholas et al 1995; Welsh et al 2002). While the shorter duration of adolescent team games may suggest a lesser depletion of CHO_{endo} stores, and therefore question the efficacy of CHO supplementation, it should be considered that adolescents may have lower endogenous glycogen stores than adults (Aucouturier et al 2008), which may offset the sparing effect of a shorter exercise bout. Furthermore, BM-relative CHO_{exo} oxidation rates may be significantly greater in young people compared to adults (Timmons et al 2003), despite the preferential use of fat as a fuel source in young people (Timmons *et al* 2007). This is likely a mechanism to preserve the lower CHO_{endo} stores (Riddell 2008). The different metabolic response of young people to exercise indicates that adult guidelines regarding CHO supplementation before and during exercise may not be appropriate for this

population. It would be of interest to study the influence of different rates of CHO ingestion by young people during intermittent endurance running. This would enable observation of whether their ability to readily oxidise CHO_{exo} elicits a dose-response relationship to CHO provision in terms of enhancing exercise performance (Jeukendrup et al 1999), and to begin the process of forming guidelines for the ingestion of CHO during intermittent endurance running in this population.

Manipulating CHO_{exo} intake could be achieved by ingesting different volumes of a 6% solution; however, ingesting larger volumes may lead to gastrointestinal distress (Shi et al 2004). Furthermore, this practice would not translate well to actual field-based team games, where there are limited opportunities to drink during matches (Clarke et al 2008). Manipulating the [CHO] of the ingested solution may also increase the risk of gastrointestinal distress (Shi et al 2004), but the minimal understanding of CHO tolerance during team games in adolescents, along with the absence of any CHO intake guidelines, provides a rationale for using different [CHO].

The aim of this study is to determine the influence of ingesting a 2, 6, and 10% CHO-E solution immediately before, and during, an intermittent endurance running protocol on the intermittent endurance capacity and sprint performance of adolescent team games players. It was hypothesised that [CHO] would significantly influence intermittent endurance capacity, but would not significantly impact sprint performance during prolonged intermittent running.

Methods

Participants

Seven team games players (five males and two females; mean age 13.3 ± 0.5 years, height 1.71 ± 0.05 m, BM 62.0 ± 6.3 kg) participated in the study. Participants were recruited from local schools and sports clubs. Inclusion criteria were that they had to be between the ages of 12-14 years, regularly participating in competitive soccer, rugby or field hockey to at least club level, free from any muscle or joint injury, and not taking medication that influences the ability to exercise. All participants were in good health at the time of the study, as determined by completion of a pre-study medical questionnaire. Participants' were either frequent or occasional users of CHO containing sports drinks.

Prior to inclusion, comprehensive written and verbal explanation of the study was given to participants and parents, and written parental informed consent was received. Each participant then gave their written assent. The study received ethical approval from the University of Edinburgh Ethics Committee.

Biological maturity status

Biological maturity was not assessed using direct observational assessment of Tanner Stages (Tanner 1962), due to ethical and consensual restrictions. Instead, biological maturity offset was assessed using the established, non-invasive equations of Mirwald et al (2002), as previously described (Phillips et al 2010). For the participants in this study, mean biological maturity offset was +1.25 years (range +0.70 to +2.68 years). Mean predicted age at peak

height velocity for females was 11.3 years (range 0 years) and for males was 13.0 years (range 12.3 to 13.8 years). This classifies the participants in this study as average maturers (Baxter-Jones et al 2005).

Preliminary Tests

Peak Running Velocity

All exercise intensities used in the main experimental protocol were based on percentages of peak running velocity (V_{peak}) as determined from a treadmill V_{peak} test. This is in contrast to the more common calculation of speed based on percentage of $\dot{V}O_{2max}$, and is believed to more accurately reflect physiological demand during team games (Bangsbo 1994). The physiological responses to incremental maximal treadmill running and free-range running have been reported to be similar (Crouter et al., 2001). Prior to undertaking theV_{peak} test, all participants walked at a self-selected speed on the treadmill (Ergo 55, Woodway, Germany) for 2 min, then completed the first four levels of the V_{peak} test as described below, to familiarise themselves with the treadmill (Lavcanska et al 2005). This also acted as a standardised warm-up. Following this familiarisation, participants sat quietly for 10 min to recover and allow any excessive anxiety to dissipate before starting the test.

The V_{peak} test, adapted from Marino et al (2004), began at 8 $km.h^{-1}$ at a gradient of 1% for one-minute, after which the speed was increased by 0.5 $km.h^{-1}$ in one-minute increments until the participant indicated they could not continue, despite strong verbal encouragement. A maximal effort was confirmed by observation of subjective symptoms of fatigue (facial flushing, unsteady gait, heavy sweating, hyperpnoea) and attainment of a HR $\geq$ 195 beats per

min (Armstrong 2007). Peak running velocity and maximum HR (HR_{max}) were calculated as the highest treadmill velocity maintained for 30 s and the highest 5 s average, respectively. After a 15 min seated recovery, participants performed 15 min of the LIST, as described below, to familiarise themselves with the running speeds required and the data collection procedures.

Experimental Design

All participants completed three trials separated by a minimum of three, and maximum of seven, days, in a randomised, counterbalanced, double-blind fashion. The three trials were as follows:

A. 2% CHO-E solution (low CHO trial – LCHO)
B. 6% CHO-E solution (moderate CHO trial – MCHO)
C. 10% CHO-E solution (High CHO trial – HCHO)

The [CHO] of both the LCHO and MCHO solutions was similar to that of commercially available CHO-E drinks. Furthermore, the [CHO] of the MCHO solution was the same as that used in previous research from this laboratory (Phillips et al 2010) and was similar to solutions used in the majority of adult work (Davis et al 1999; Nicholas et al 1995; Welsh et al 2002). The HCHO solution was employed, as solutions with a [CHO] >10% are rarely used in contemporary research due to current adult guidelines regarding fluid and CHO intake during prolonged, steady-state exercise (Jeukendrup 2004). No such guidelines currently exist for young people. Therefore, the use of a [CHO] greater than 10% currently

has no empirical support and, due to the lack of knowledge of CHO tolerance during prolonged intermittent exercise in young people, no ethical basis.

The CHO was 100% maltodextrin (High5 Ltd, Bardon, UK). Commercially available electrolyte tablets (High5 Ltd, Bardon, UK) were used in all solutions (one tablet dissolved per 500 ml of solution), yielding the following electrolyte concentrations per L: sodium, 250 mg; magnesium, 60 mg; potassium, 90 mg; calcium, 20 mg. The electrolyte tablets also contained a flavouring (citrus, berry, or cherry-orange). Prior to the first trial, each participant was asked which flavour they would prefer. The participants' chosen flavour was then used for all three of their trials. Therefore, within-participants, all solutions were matched for colour, taste, texture, and feeling within the mouth. Participants were requested to refrain from heavy physical activity for 48 h before each trial. They were also asked to record their food and fluid intake, including the portion size of all food consumed and the volume of all fluid ingested, for 24 h before the first trial. This diet was replicated prior to trials two and three to standardise muscle and hepatic glycogen concentrations and hydration status. Participants were not requested to record food and fluid intake in the depth of detail that would have enabled a subsequent dietary composition analysis. Requesting this would have placed greater stress on extremely time-pressured participants and their parents, and may have negatively affected adherence to the dietary record, and retention of participants through the full study.

Experimental Protocol

Standing height was measured using a free-standing adjustable stadiometer (Seca, model no. 2251821009, Germany). After voiding and urinating, if necessary, dry nude BM was

recorded (Seca Digital, model no. 7052321009, Germany). Participants were then fitted with a HR monitor chest strap and watch (Polar RS400, Polar Electro Oy, Finland) and sat quietly for 5 min, after which a standardised warm-up consisting of jogging, striding and dynamic stretching was undertaken for 10 min. Immediately following the warm-up, participants sat and were instructed to consume the prescribed solution (5 $ml.kg^{-1}$ BM) during the 5 min before commencing exercise (Nicholas et al 1995). Once this initial bolus had been consumed, participants were asked to state which solution they believed was being prescribed.

The LIST was conducted indoors, on a level rubber floor, as described elsewhere (Phillips et al 2010). Briefly, participants completed four blocks of part A of the LIST separated by 3 min seated recovery, followed by an intermittent run to exhaustion (part B). Participants consumed the solution (2 $ml.kg^{-1}$ BM) in the recovery period between each 15 min block and in the recovery period before commencing part B. After the measurement of post-exercise BM, participants were asked again to state which solution they believed they had received during the protocol. This was done in order to compare their response with their pre-exercise choice, and observe whether their experiences during the exercise bout prompted them to change their mind about which solution they had consumed during the protocol. Participants' were clearly informed that they were free to change their mind from their pre-exercise solution choice, or to keep their selection the same.

Measurements

Heart rate was recorded at 5 s intervals throughout the V_{peak} test and the experimental protocol using short-range telemetry. Data was retrieved and downloaded onto a computer

software program (Polar ProTrainer 5, Polar Electro Oy, Finland) for subsequent analysis. Ambient temperature and relative humidity were recorded immediately before the start of the protocol and at the end of each 15 min block in part A using a digital hygro-thermometer (Tako Astatic Technology, Malaysia). Ratings of perceived exertion were recorded during the first shuttle of the final walking phase of each 15 min block in part A and at exhaustion in part B using the Children's Omnibus Scale of Perceived Exertion (0-10 scale). This scale has been validated for use with participants of the age range in this study (Roemmich et al 2006). Gut fullness (GF) and gastric discomfort (GD) were assessed immediately on completion of each 15 min block in part A and at exhaustion in part B via anchored 10 point scales (1 = not at all, 10 = extremely; van Nieuwenhoven et al 2005). Sprint times were measured in one direction by two wireless infrared single-beam photoelectric cells (Speed Trap 2, Gill Athletics, Illinois) placed 15 m apart. If participants needed to urinate at any time from the onset of the protocol until completion of the measurement of post-exercise BM, they did so into a measuring jug, with this volume incorporated into the BM loss calculation. No participant needed to urinate during the protocol in the current study. Body mass loss was calculated from the difference between pre- and post-exercise nude BM, corrected for fluid intake and urine output. Sweat rate ($L.h^{-1}$) was calculated using the equation: (Pre-exercise BM (kg) + fluid ingested (L) – urine output (L) – post-exercise BM (kg)) / protocol duration (min) x 60 (Edwards et al 2007). This calculation does not account for BM loss due to fuel oxidation and respiratory fluid loss, but it is unlikely these would differ between trials (Edwards et al 2007).

Statistical Analysis

The Shapiro-Wilk test for normality was employed on all data sets. One-way repeated measures ANOVA compared between trials differences in fluid and CHO intake, pre-exercise BM, BM loss and SR, and time to exhaustion, HR, RPE, GF and GD at exhaustion in part B. Bonferroni pairwise comparisons and simple contrast analysis were used to explore main effects of fluid and CHO intake and time to exhaustion, respectively. Two way (solution x time) ANOVA analysed mean relative humidity, mean sprint times and mean peak sprint times, HR, RPE, GF and GD during part A. Bonferroni pairwise comparisons explored the main effect for RPE, and paired t-tests with Bonferroni correction explored main effects for mean sprint times, mean peak sprint times, HR, GF and GD. Friedman tests with Bonferroni correction analysed between trials differences in mean ambient temperature at all time points, with a Friedman's test employed to analyse the main effect of time for the grouped trials data. Chi-square analysis assessed the frequency distribution of solution choice responses. Effect sizes (ES) were calculated using partial eta squared (η^2) values, which were square rooted to give correlation coefficients (Field 2005). Where post-hoc paired t-tests with Bonferroni correction were performed, ES was calculated using the equation of Rosnow and Rosenthal (2005) to produce correlation coefficients. Effect sizes were defined as small (r = 0.1-0.3), moderate (r = 0.3-0.5), large (r = 0.5-0.7), very large (r = 0.7-0.9), and nearly perfect (r = 0.9-1.0) based on the classifications of Hopkins (2006). Data are mean ± SD. With the exception of analyses using the Bonferroni correction, significance was set at $P < 0.05$.

Results

Preliminary Tests

Mean V_{peak} attained in the incremental treadmill run to exhaustion was 14.4 ± 1.2 $km.h^{-1}$. Mean HR_{max} and RPE at exhaustion were 196 ± 6 beats per min and 9.3 ± 0.5, respectively.

Distance covered and time to exhaustion

By design, distance covered during part A was the same in all three trials (7.1 ± 0.3 km). Time to exhaustion was significantly influenced by solution ($F_{2, 12}$ = 6.1, P < 0.05, r = 0.71), and was 34% greater in the MCHO trial compared with the HCHO trial (5.5 ± 0.8 vs. 4.1 ± 1.5 min, P < 0.05, r = 0.76), and by 14.6% compared with the LCHO trial (4.8 ± 1.2 min), although this was not statistically significant (P = 0.10, r = 0.63). Time to exhaustion in the LCHO trial was 17.1% greater than the HCHO trial, but was not statistically significant (P = 0.09, r = 0.63). Distance covered in part B was significantly greater in the MCHO trial compared with the HCHO trial (931 ± 172 vs. 706 ± 272 m, P < 0.05, r = 0.76), but not the LCHO trial (811 ± 230 m, P = 0.09, r = 0.63). Distance covered was not significantly different between the LCHO and HCHO trials (P = 0.11, r = 0.61).

Sprint times

The mean time of all sprints, and the mean of participants' peak sprint time only, in each block of part A of the LIST are shown in figure 1A and 1B, respectively. There was a trend for mean sprint times to be slower throughout exercise in the HCHO trial compared with the other two trials, but no main effect of solution was present ($F_{2, 10} = 1.1$, $P = 0.38$, $r = 0.42$). Similarly, there was no interaction effect (solution x time, $F_{2.1, 10.3} = 0.89$, $P = 0.44$, $r = 0.39$). There was a main effect of time ($F_{1.1, 5.5} = 8.6$, $P < 0.05$, $r = 0.79$), with sprint time increasing significantly with each successive exercise block ($P < 0.05$, $r = 0.56$, 0.82 and 0.55, respectively). Peak sprint time for each exercise block showed a trend for slower times in the HCHO trial compared with the other two trials, but no main effect of solution ($F_{2, 10} = 1.1$, $P = 0.37$, $r = 0.42$) or interaction ($F_{6, 30} = 0.6$, $P = 0.72$, $r = 0.33$) was found. There was a main effect of time ($F_{3, 15} = 8.3$, $P < 0.005$, $r = 0.79$), with peak sprint time significantly slower in block 3 than block 2 ($P < 0.001$, $r = 0.75$). There was no significant difference between blocks 1 and 2 ($P = 0.22$, $r = 0.30$) or 3 and 4 ($P = 0.60$, $r = 0.10$).

PLEASE PLACE FIGURE 1A and 1B HERE

Heart rate, ratings of perceived exertion, and gastric measures

Mean HR and RPE during part A of the LIST, and mean peak HR and RPE at exhaustion in part B are shown in table 1. Heart rate was lower in the LCHO trial at all time points in part A, but there was no significant treatment ($F_{2, 8} = 1.8$, $P = 0.23$, $r = 0.56$) or interaction ($F_{6, 24} = 1.7$, $P = 0.62$, $r = 0.40$) effect. There was a main effect of time for HR in part A ($F_{3, 12} = 32.1$, $P < 0.001$, $r = 0.94$). Heart rate in block 2 was significantly greater than block 1 ($P <$

0.01, $r = 0.98$). There was no significant difference between blocks 2 and 3 ($P = 0.48$, $r = 0.76$) or 3 and 4 ($P = 1.0$, $r = 0.22$). Peak HR at exhaustion in part B was not significantly different between trials ($F_{1.1, 6.8} = 0.67$, $P = 0.46$, $r = 0.32$). Ratings of perceived exertion were similar at all time points between trials, with no significant differences found ($F_{2, 12} = 1.3$, $P = 0.32$, $r = 0.42$). No interaction effect was present ($F_{6, 36} = 0.3$, $P = 0.53$, $r = 0.35$). There was a main effect of time ($F_{1.1, 6.5} = 36.0$, $P < 0.005$, $r = 0.93$), with RPE significantly greater in block 2 than block 1 ($P < 0.05$, $r = 0.97$) and in block 4 than block 3 ($P < 0.001$, $r = 0.99$). There was no significant difference between blocks 2 and 3 ($P = 0.41$, $r = 0.95$), and no significant between trials difference in RPE at exhaustion ($F_{1, 6} = 1.0$, $P = 0.36$, $r = 0.38$).

PLEASE PLACE TABLE 1 HERE

Mean GF and GD during part A of the LIST and at exhaustion in part B are shown in table 2. Mean GF was not significantly influenced by solution ($F_{2, 12} = 1.1$, $P = 0.36$, $r = 0.40$), and there was no interaction effect ($F_{6, 36} = 1.0$, $P = 0.43$, $r = 0.38$). There was a significant effect of time on GF ($F_{3, 18} = 3.3$, $P < 0.05$, $r = 0.59$). This main time effect was just under the stated alpha figure of $P < 0.05$, and specific differences between time points could not be determined using *post hoc* analyses. Effect sizes for the differences between blocks 1 and 2, 2 and 3, and 3 and 4 were $r = 0.10$, 0.22 and 0.48, respectively. Gut fullness at exhaustion was not significantly different between trials ($F_{2, 12} = 2.2$, $P = 0.16$, $r = 0.51$). Despite the significant main effect of time, GF scores during part A of the LIST were modest. There was no treatment ($F_{2, 12} = 0.4$, $P = 0.68$, $r = 0.25$) or interaction ($F_{6, 36} = 1.8$, $P = 0.14$, $r = 0.48$) effect on GD, but there was a main effect of time ($F_{3, 18} = 3.9$, $P < 0.05$, $r = 0.63$). As with GF, specific differences could not be determined *post hoc*. Effect sizes for the differences between blocks 1 and 2, 2 and 3, and 3 and 4 were $r = 0.46$, 0.10 and 0.40, respectively.

Gastric discomfort at exhaustion was similar across all trials ($F_{2, 12}$ = 0.27, P = 0.77, r = 0.21). Gastric discomfort scores during part A of the LIST were moderate.

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Body mass loss and sweat rate

Mean pre-exercise dry nude BM was not significantly different between trials ($F_{2, 12}$ = 0.1, P = 0.92, r = 0.11). Mean BM loss was 1.0 ± 0.2, 1.0 ± 0.2, and 1.0 ± 0.4 kg in the LCHO, MCHO and HCHO trials, respectively ($F_{2, 12}$ = 0.11, P = 0.90, r = 0.13), equating to a mean loss of 1.62 ± 0.37, 1.63 ± 0.24, and 1.54 ± 0.49% of pre-exercise BM, respectively ($F_{2, 12}$ = 0.24, P = 0.79, r = 0.19). Mean SR was 0.78 ± 0.15, 0.78 ± 0.13, and 0.76 ± 0.28 $L.h^{-1}$ in the LCHO, MCHO and HCHO trials, respectively ($F_{2, 12}$ = 0.03, P = 0.97, r = 0.07), equating to a BM-relative mean sweat loss of 12.63 ± 2.81, 12.53 ± 1.75, and 12.18 ± 3.86 $ml.kg^{-1}$ $BM.h^{-1}$, respectively ($F_{2, 12}$ = 0.09, P = 0.91, r = 0.12).

Blinding

After consuming the initial bolus of the solution immediately prior to exercise, one participant (14%) correctly identified all solutions and six (86%) failed to do so. Chi square analysis of the responses in the MCHO trial found a non-significant deviation from the expected response frequency ($\chi^2(1)$ = 3.6, P = 0.16). Post-exercise, only one participant correctly guessed all three solutions, and this was the same participant who guessed all three correctly pre-exercise. In the LCHO and MCHO trials, one participant (14%) changed their mind post-exercise and correctly guessed the solution when they had guessed incorrectly

prior to exercise. In the HCHO trial, no participant identified the correct solution post-exercise after having chosen incorrectly pre-exercise.

Ambient temperature and relative humidity, fluid and carbohydrate intake

Mean ambient temperature and relative humidity during the LIST are shown in table 3. Mean ambient temperature was not significantly different between trials at any time point, therefore the data for all three trials was grouped for analysis of a main effect of time. Mean ambient temperature rose from 18.0 ± 1.7ºC immediately pre-exercise to 18.3 ± 1.7 ºC at the end of part A of the LIST ($\chi^2(4) = 39.3$, $P < 0.001$). Mean relative humidity was not significantly different between ($F_{2, 12} = 0.06$, $P = 0.94$, $r = 0.10$) or within ($F_{1.6, 9.6} = 4.1$, $P = 0.06$, $r = 0.64$) trials, and there was no interaction effect ($F_{2.2, 2.4} = 0.90$, $P = 0.46$, $r = 0.36$).

Mean fluid intake was 811 ± 83, 810 ± 82, and 810 ± 84 ml ($F_{2, 12} = 0.05$, $P = 0.95$, $r = 0.09$) in the LCHO, MCHO and HCHO trials, respectively. Absolute CHO intake in the LCHO, MCHO and HCHO trials was 12.7 ± 1.3, 37.6 ± 3.7, and 64.0 ± 7.3 $g.h^{-1}$ ($F_{1.0, 6.1} = 497.0$, $P < 0.001$, $r = 0.99$), or 0.21 ± 0.02, 0.63 ± 0.06, and 1.07 ± 0.02 $g.min^{-1}$ ($F_{1.0, 6.1} = 481.6$, $P < 0.001$, $r = 1.0$). Body mass-relative CHO consumption was 0.26, 0.78, and 1.3 $g.kg^{-1}$ BM in the LCHO, MCHO and HCHO trials, respectively.

PLEASE PLACE TABLE 3 HERE

Discussion

This study demonstrates that ingestion of a 6% CHO-E solution significantly improves the intermittent endurance capacity of adolescent team games players during intermittent endurance running compared with a 10% solution. A non-significant trend for improved intermittent endurance capacity with the 6% compared with a 2% solution, and the 2% compared with a 10% solution, was also found. No significant influence of [CHO] was found for sprint performance during the protocol.

Time to exhaustion

The greatest intermittent endurance capacity was achieved in the MCHO trial. This suggests that adult guidelines for CHO ingestion during prolonged moderate- to high-intensity exercise (Jeukendrup 2004) do not apply to adolescent team games athletes during intermittent endurance running. In support of this adult-child difference, Nassis et al (1998) failed to find a significant improvement in intermittent endurance capacity in adults during prolonged intermittent treadmill running with ingestion of CHO at very similar rates to that of the MCHO trial in the current study (0.6 $g.min^{-1}$; 34 $g.h^{-1}$).

The minimum absolute rate of CHO ingestion that has been demonstrated to enhance endurance capacity during prolonged cycling in adults is 16 $g.h^{-1}$ (Jeukendrup 2004), equating to 0.26 $g.min^{-1}$, whereas any further CHO ingestion above a rate of ~1-1.1 $g.min^{-1}$ does not further increase the rate of CHO_{exo} oxidation, provided the composition of ingested CHO remains the same (Jeukendrup 2004). In the current study, the rate of CHO ingestion in the LCHO trial may not have facilitated absorption of sufficient CHO into the systemic

circulation to enable exercise enhancement (Rogers et al 2005) The reasons behind the inferior intermittent endurance capacity in the HCHO trial are unclear. It does not appear that CHO ingestion simply exceeded the maximal rate of CHO absorption and/or oxidation of the participants, as in this case a similar intermittent endurance capacity between the HCHO and MCHO trials would have been expected. This requires further study, perhaps by focussing initially on potential modulators of CHO_{exo} oxidation (Jeukendrup 2004; Shi & Passe 2010). However, it should also be noted that there was a larger variation in time to exhaustion values for the HCHO trial, perhaps representing a greater individual variation in response to this CHO dose. Conversely, this may also have been due to the relatively small sample size. While this study was not designed to identify enhancement mechanisms due to ethical and consensual restrictions, it does provide initial indirect support for the existence of low and high CHO ingestion thresholds during intermittent endurance running in adolescents, below and above which the efficacy of CHO does not appear to be maximised, in line with adult findings (Jeukendrup 2004). Interestingly, these thresholds appear to be at different ingestion rates for adolescents than adults. Clearly, more work is required to confirm the relative influence of different [CHO] during intermittent endurance running in adolescents, and to provide data on the metabolic response to these [CHO], which may help to explain the performance data.

Sprint Performance

The lack of influence of CHO on sprint performance, along with a progressive, treatment-independent increase in sprint duration with time, in the current study is in line with previous work from this laboratory (Phillips et al 2010), and the reader is referred here for further discussion on these findings. When the results of these two studies are combined, it can be

inferred that CHO supplementation across a range of ingestion rates does not significantly influence the sprint performance of adolescent team games players during intermittent endurance running, in line with most adult work (Davis et al, 1999; Nicholas et al., 1995).

The mean increase in sprint time from the first to the last block of part A in all trials is greater than that recorded in some adult work (0.08 sec for both trials; Ali et al 2007), in line with Phillips et al (2010). This provides further confirmation that adolescent team games players do not appear to display a greater fatigue resistance than adults during sprinting in the LIST, as may have been expected (Ratel et al 2002).

Heart rate, ratings of perceived exertion, and gastric measures

The lack of a treatment effect on HR during part A of the LIST in the current study agrees with our previous findings (Phillips et al 2010) and most adult research (Ali et al 2007; Nicholas et al 1995; Welsh et al 2002). Mean HR during part A of the LIST was in agreement with values reported during outdoor 11-a-side and indoor 5-a-side soccer matches in recreational and elite young players (Castagna et al., 2007; Strøyer et al., 2004).

Heart rate at exhaustion in part B of the current study is in contrast to our previous investigation, which reported a significantly greater HR at exhaustion in the CHO trial (Phillips et al 2010). It is possible that this was simply an artefact of the particular participant population used in that study and not, as suggested at the time, a mechanistic indicator of a metabolic and/or perceptual response to CHO supplementation. Alternatively, a perceptual mechanism of CHO efficacy in adolescent team games players may exist, but may be participant-dependent. More work should be undertaken to clarify this.

Data from the current study lends further support to our previous finding that CHO supplementation does not modulate RPE during intermittent endurance running in adolescents (Phillips et al 2010), although it should be considered that a non-CHO trial was not included in the current study. This suggests that CHO supplementation does not elicit centrally-mediated alterations in adolescents that modulate effort perception during exercise, and may further indicate that enhancements in intermittent endurance capacity with CHO ingestion in this population are of a metabolic nature. However, as mentioned in the previous paragraph, it may be too early to rule out a possible influence of CHO on effort perception at exhaustion.

No increase in RPE was observed in block 3 of part A of the LIST. Both mean sprint and mean peak sprint times significantly slowed during block 3 of the LIST, which may have had an attenuating influence on RPE in block 3. However, a slower sprint time may relate to a less favourable metabolic condition for sprinting (Bangsbo et al 2006), not necessarily a reduced effort from participants. Furthermore, in our previous study mean sprint and mean peak sprint time slowed significantly in block 3 of the LIST, with no corresponding attenuation in RPE (Phillips et al 2010). The non-significant increase in RPE in block 3 of the LIST in the current study may be a result of the low participant number, which is supported by the almost perfect ES for this time point.

The current study indicates that 2, 6, and 10% CHO-E solutions are equally well tolerated by adolescents during intermittent endurance running. This conforms to previous findings from this laboratory regarding tolerance to CHO-E solutions and CHO gels in adolescents during prolonged intermittent exercise (Phillips et al 2010; Phillips et al unpublished data).

Mechanisms behind the influence of time on gastric variables are discussed elsewhere (Phillips et al 2010).

Body mass loss and sweat rate

When the results of the current, and our previous, study are considered, it appears that ingestion of CHO across a range of concentrations does not alter the BM loss or SR responses of adolescents to intermittent endurance running. The BM loss and SR data from the current study and that of Phillips et al (2010) currently represent the only published data of its kind in adolescents during intermittent endurance running, therefore comparison of values with other related work is not possible at this time.

Blinding

It appears that the blinding procedures used in this study were effective. Furthermore, the data indicates that exercise did not provide any cues enabling participants to more accurately identify the three solutions. Interestingly, however, it does appear that some cues were provided to the participants during exercise that led them to falsely believe that they had not received the HCHO solution. It is impossible to speculate as to what these cues may have been, and whether they were perceived as positive or negative, without knowing what the individual participants' beliefs were pre-exercise regarding the HCHO solution. Therefore, the influence of intermittent endurance running exercise on adolescents' perceptions of CHO administration should be investigated further, considering the potential influence of an individuals perception of the treatment they believe they have received on their subsequent exercise performance (Beedie et al 2007).

Preliminary tests: peak running velocity and maximum heart rate

The mean V_{peak} of 14.4 $km.h^{-1}$ in the current study is very similar to that reported in our previous work (Phillips et al 2010), and suggests our participants were of a notably higher training status than international population means (Sandercock et al 2008), although protocol differences should be considered when interpreting V_{peak} data between studies. The mean HR_{max} and RPE values recorded in the current study are again similar to our previous work, and indicate our participants provided a maximal effort during the incremental test (Armstrong, 2007). The similar V_{peak}, HR and RPE data in the current study compared with our previous work (Phillips et al 2010) indicates that the participants used in these two studies were of a similar training status, strengthening the comparisons made throughout this discussion.

Conclusion

Ingestion of a 6% CHO-E solution significantly improves the intermittent endurance capacity of adolescent team games players during intermittent endurance running compared with a 10% solution. A non-significant trend for greater intermittent endurance capacity was reported with ingestion of the 6% compared with the 2% solution, and the 2% compared with the 10% solution. Carbohydrate concentration did not significantly influence sprint performance or physiological responses to intermittent endurance running. Future research should build on these findings in order to further develop guidelines for optimal CHO ingestion by adolescents during team games.

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Ethical Declaration

The authors confirm that the conduct of this study complied fully with current Scottish law, and with the full ethical approval of the University of Edinburgh, Moray House School of Education Ethics Committee.

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Tables

Table 1 Mean heart rate (beats per min) and mean ratings of perceived exertion during part A of the LIST, and peak heart rate and ratings of perceived exertion at exhaustion in part B for all trials.

	Period of the LIST				
	Block 1	Block 2	Block 3	Block 4	Exhaustion
Mean heart rate (beats per min)					
LCHO	159 ± 7	164 ± 7***	165 ± 7	165 ± 7	189 ± 3
MCHO	162 ± 6	168 ± 5***	170 ± 6	169 ± 5	190 ± 4
HCHO	162 ± 5	168 ± 6***	168 ± 6	168 ± 5	190 ± 4
Mean ratings of perceived exertion					
LCHO	4.6 ± 1.1	6.0 ± 0.82*	7.4 ± 0.98	7.6 ± 1.1**	9.4 ± 0.53
MCHO	4.4 ± 0.98	6.1 ± 0.70*	6.7 ± 0.95	8.0 ± 0.82**	9.3 ± 0.49
HCHO	4.4 ± 0.98	6.0 ± 1.0*	7.1 ± 0.70	8.0 ± 0.82**	9.3 ± 0.49

Data are mean ± SD (n = 7)

LCHO = low CHO trial; MCHO = moderate CHO trial; HCHO = high CHO trial

*** significantly greater than block 1, $P < 0.01$; * significantly greater than previous block, $P < 0.05$; ** significantly greater than previous block, $P < 0.001$

Table 2 Mean gut fullness and gastric discomfort ratings during part A of the LIST, and at exhaustion in part B, for all trials.

	Period of the LIST				
	Block 1	Block 2	Block 3	Block 4	Exhaustion
Mean gut fullness ratings					
LCHO	4.1 ± 1.7	4.7 ± 1.3	4.7 ± 1.1	5.3 ± 1.3	5.1 ± 1.1
MCHO	4.1 ± 1.6	3.9 ± 1.9	4.0 ± 1.7	4.7 ± 1.7	5.3 ± 1.3
HCHO	3.7 ± 1.4	3.7 ± 1.1	4.3 ± 1.6	4.3 ± 1.1	4.7 ± 0.80
Mean gastric discomfort ratings					
LCHO	2.1 ± 1.1	3.1 ± 1.2	3.0 ± 1.3	3.1 ± 1.5	4.0 ± 1.5
MCHO	2.9 ± 1.3	3.3 ± 1.4	3.3 ± 1.6	3.4 ± 1.7	4.3 ± 1.8
HCHO	2.3 ± 1.9	2.4 ± 1.1	2.9 ± 1.2	4.0 ± 1.9	4.1 ± 2.0

Data are mean ± SD (n = 7)

LCHO = low CHO trial; MCHO = moderate CHO trial; HCHO = high CHO trial

A main effect of time was found for GF and GD ($P < 0.05$)

Table 3 Mean ambient temperature (°C) and relative humidity (%) immediately before, and during, part A of the LIST.

	Period of the LIST				
	Pre-exercise	Block 1	Block 2	Block 3	Block 4
Mean ambient temperature (°C)					
LCHO	18.0 ± 1.8	18.1 ± 1.9	18.1 ± 1.9	18.2 ± 1.9	18.2 ± 1.9
MCHO	17.8 ± 1.4	17.9 ± 1.4	18.0 ± 1.4	18.0 ± 1.3	18.1 ± 1.3
HCHO	18.3 ± 2.2	18.4 ± 2.1	18.4 ± 2.1	18.5 ± 2.1	18.5 ± 2.1
Mean relative humidity (%)					
LCHO	40.6 ± 5.5	40.1 ± 6.1	39.9 ± 6.1	39.4 ± 5.9	39.0 ± 6.0
MCHO	40.7 ± 8.4	40.4 ± 8.4	40.1 ± 8.6	39.7 ± 8.6	39.6 ± 9.2
HCHO	40.6 ± 9.0	41.0 ± 8.3	41.1 ± 8.2	41.0 ± 8.3	40.0 ± 8.8

Data are mean ± SD (n = 7)

LCHO = low CHO trial; MCHO = moderate CHO trial; HCHO = high CHO trial

A main effect of time was found for the grouped mean ambient temperature data ($P < 0.01$)

Figure Captions

Figure 1 Mean sprint time (A) and mean peak sprint time (B) during part A of the LIST for allboth trials. * significantly greater than previous block, $P < 0.05$; ** significantly greater than previous block, $P < 0.001$. ($n = 6$).