Ingesting a 6% carbohydrate-electrolyte solution improves performance and endurance capacity during intermittent, high-intensity shuttle running in adolescent team games players aged 12 - 14 years

Ingesting a 6% carbohydrate-electrolyte solution improves endurance capacity, but not sprint performance, during intermittent, high-intensity shuttle running in adolescent team games players aged 12 – 14 years

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Abstract

The main aim of this study was to investigate the influence of consuming a 6% carbohydrate-electrolyte (CHO-E) solution on the intermittent, high-intensity endurance performance and capacity of adolescent team games players. Fifteen participants (mean age 12.7 ± 0.8 years) performed two trials separated by 3-7 days. In each trial, they completed 60 min of exercise composed of four 15 min periods of part A of the Loughborough Intermittent Shuttle Test, followed by an intermittent run to exhaustion (part B). In a double-blind, randomised, counterbalanced fashion participants consumed either the 6% CHO-E solution or a non-carbohydrate (CHO) placebo (5 ml.kg^{-1} BM) during the 5 min pre-trial and after each 15 min period of part A (2 ml.kg^{-1} BM). Time to fatigue was increased by 24.4% during part B when CHO was ingested (5.1 ± 1.8 vs. 4.1 ± 1.6 min, $P < 0.05$), with distance covered in part B also significantly greater in the CHO trial (851 ± 365 vs. 694 ± 278 m, $P < 0.05$). No significant between-trials differences were observed for mean 15 m sprint time ($P = 0.35$), peak sprint time ($P = 0.77$), or heart rate ($P = 0.08$) during part A. These results demonstrate, for the first time, that ingestion of a CHO-E solution significantly improves the intermittent, high-intensity endurance running capacity of adolescent team games players during an exercise protocol designed to simulate the physiological demands of team games.

Key Words: Carbohydrate; intermittent, high-intensity exercise; adolescent; endurance

Introduction

Physiological studies of adult field-based team games (soccer, rugby and field hockey) suggest a mean whole-game exercise intensity of 70-80% $\dot{V}O_{2max}$, analogous to prolonged moderate to high-intensity steady state exercise (Bangsbo 1994). As with prolonged steady state exercise, significant glycogen depletion can occur during team games, which in soccer can reduce the amount of total and high-intensity work completed, distance covered, and the number of sprints achieved, particularly in the second half of a game (Balsom et al 1999; Saltin 1973). This evidence of muscle glycogen depletion and performance decrement suggests that ingestion of CHO solutions during team games may be beneficial.

Nicholas et al (1995) conducted the first standardised, well-controlled laboratory study to investigate CHO supplementation during exercise designed to replicate the demands of team games. Using the Loughborough Intermittent Shuttle Test (LIST), ingestion of a 6.9% carbohydrate-electrolyte (CHO-E) solution enabled a 33% longer time to exhaustion during intermittent, high-intensity running compared with a placebo (PLA). No significant between-trials difference was found for exercise performance, measured as repeated 15 m sprint time. Subsequent research on CHO supplementation during the LIST supports this initial finding on exercise capacity in adults (Ali et al 2007; Davis et al 2000; Welsh et al 2002), with only two studies finding significant improvement in sprint performance (Ali et al 2007; Welsh et al 2002)

To date, all published research investigating CHO ingestion during simulated team games has used adult participants. Between 2002-2007~3.4 million people aged 6-16 years in England and Scotland regularly participated in soccer, rugby or field hockey (Malina 2005;

SportScotland 2008). This large population, coupled with anecdotal evidence of children and adolescents consuming commercially available CHO-E drinks during team games training and competition, provides a rationale for investigation into the efficacy of this practice for this demographic.

Adolescent substrate utilisation data provides another rationale. Adolescents typically exhibit an exercising metabolic profile consisting of greater fat and lower CHO oxidation than adults (Aucouturier et al 2008), although this is maturation dependent (Timmons et al 2007). However, when 12 year old boys consumed a 6% CHO solution during 60 min cycling at 70% $\dot{V}O_{2max,}$ exogenous CHO oxidation was significantly greater, and contributed significantly more to energy expenditure, than in adults (Timmons et al 2007). This could be a mechanism to preserve endogenous CHO stores, which may be lower than that of adults (Timmons et al 2003). Whatever the exact mechanism, this intriguing finding implies that adolescents are able to readily access exogenously delivered CHO. Furthermore, Riddell et al (2001) demonstrated a significant enhancement in endurance capacity when 10-14 year old males consumed CHO during a 90 min cycle at 55% $\dot{V}O_{2max}$ followed by a cycle to exhaustion at 90% PPO. This data suggests that consuming CHO during prolonged intermittent, high-intensity exercise may be of benefit to this population. However, no data on substrate use in adolescents during prolonged intermittent exercise is currently available.

The little work that exists on intermittent exercise in young people has shown that children and adolescents have a greater ability than adults to resist fatigue during repeated bouts of sprinting (Ratel et al 2002; Zafeiridis et al 2005). Ratel et al (2002) showed that peak power output (PPO) during repeated 10 s cycling sprints declined more consistently with increasing age, inferring that the ability to resist fatigue is inversely related to maturity (Zafeiridis et al

2005). This inherently better fatigue resistance during repeated sprints suggests that any benefits of CHO supplementation during prolonged intermittent exercise in adolescents would most likely manifest in improved intermittent endurance capacity (defined as time to exhaustion during intermittent running) as opposed to exercise performance (defined as repeated 15 m sprint times).

The aim of this study is to determine whether ingestion of a 6% CHO-E solution immediately prior to, and during, a simulated team games protocol improves the intermittent, high-intensity endurance performance and capacity of 12-14 year old team games players.

Methods

Participants

Fifteen team games players (10 males and 5 females; mean age 12.7 ± 0.8 years, height 1.66 ± 0.09 m, body mass (BM) 55.6 ± 10.4 kg) participated in the study. Participants were recruited from local schools and sports clubs. Inclusion criteria were to be between the ages of 12-14 years, regularly participating in competitive team games (football, 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.

Prior to inclusion, comprehensive written and verbal explanation of the study was provided to participants and parents, and written parental informed consent was received. Subsequently, written child assent was gained. The study received ethical approval from the University of Edinburgh ethics committee.

Biological maturity status

Due to ethical and consensual restrictions regarding direct observational assessment of Tanner stages, biological maturity offset was assessed using established, non-invasive equations (Mirwald et al 2002). The equations estimated the number of years each participant was from peak height velocity (PHV) using anthropometric variables and chronological age. A negative offset represented the number of years the participant was from reaching PHV, with a positive offset representing the number of years since the

participant reached PHV. A coefficient of determination of $r^2 = 0.89$ has been reported for the male and female equations, with Mirwald et al (2002) stating that biological maturity offset can be estimated to within ± 1 year 95% of the time. For the participants in this study, mean biological maturity offset was +0.51 years (range -1.51 - +1.27 years). Mean predicted age at PHV (APHV) for females was 11.9 years (range 11.4 - 12.2 years) and for males was 13.2 years (range 12.4 - 14.4 years). This classifies the participants in this study as average maturers (Karlberg 2002).

Preliminary Tests

Peak Running Velocity

The participants in this study all had different levels of experience running on motorised treadmills. Therefore, prior to undertaking the peak running velocity (V_{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 enabled the participants to relax and become comfortable on the treadmill, and the investigator to ensure the participants safety was not at risk from instability while running. The validity of the test was improved by this familiarisation, as the participants were able to execute a more natural running technique from the onset of the test. It also acted as a standardised warm-up for each participant. Following this familiarisation, participants sat quietly for 10 min to recover and allow any residual 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 that 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 ≥ 195 $b.min^{-1}$ (Armstrong 2007). Peak running velocity and maximum heart rate (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 two trials separated by a minimum of three, and maximum of seven, days. During each trial participants consumed either a 6% CHO-E solution (CHO trial) or a non-CHO PLA (PLA trial). The CHO was 100% maltodextrin (High5 Ltd, Bardon, UK). Commercially available electrolyte tablets (High5 Ltd, Bardon, UK) were used in both the CHO and PLA solutions (one tablet dissolved per 500 ml of solution), yielding the following electrolyte concentrations per litre: sodium, 250 mg; magnesium, 60 mg; potassium, 90 mg; calcium, 20 mg. These tablets also contained flavouring (citrus, berry, or cherry-orange), and were chosen at random for each participant. Within-participants, solutions were matched for colour, taste and texture. All trials were randomised, counterbalanced, and double-blinded to control for order effects and experimenter bias. Participants were requested to refrain from heavy physical activity for 48 h before each trial. Additionally, they were 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 trial two to standardise muscle and hepatic glycogen concentrations and hydration status.

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). After attaching the heart rate (HR) monitor chest strap and watch (Polar RS400, Polar Electro Oy, Finland), participants sat quietly in a chair 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 in a chair and were instructed to consume the prescribed solution (5 $ml.kg^{-1}$ BM) during the 5 min before commencing exercise (Nicholas et al 1995).

The LIST was conducted over 20 m on a level, firm rubber floor and consisted of a set pattern of intermittent exercise performed in four 15 min blocks separated by 3 min seated recovery (part A), 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. A schematic of the full protocol is in Figure 1. All exercise intensities were based on percentages of V_{peak} as determined from the V_{peak} test. This is opposed 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 order of each cycle of exercise in part A was as follows:

1. 3 x 20 m at walking pace (1.3 $m.sec^{-1}$)
2. 1 x 20 m sprint
3. 3 x 20 m at running speed corresponding to 55% V_{peak}
4. 3 x 20 m at running speed corresponding to 95% V_{peak}

(INSERT FIGURE 1 HERE)

Part B consisted of single 20 m shuttles alternating between running speeds corresponding to 55 and 95% V_{peak} until exhaustion. Exhaustion was defined as the inability to maintain the required pace for three consecutive shuttles at the higher running velocity. Running and walking speeds were dictated using a series of pre-programmed beeps from an audio CD played on a laptop computer. Throughout the protocol, participants were immediately informed if they fell behind the required pace, and were encouraged to adjust their speed to re-gain the correct pace. This was usually accomplished by the end of the next shuttle. If in doing so participants arrived at the end of the next shuttle in advance of the pacing signal, they were required to wait until they heard the signal before commencing the next shuttle. This was to prevent possible confusion due to participants running out of synchronisation with the signals. Participants were verbally encouraged to perform maximally during the sprints and during part B, and were not made aware of their performance during any part of the LIST. On completion of the protocol, participants removed excess sweat from their skin and urinated if required, whereupon dry nude BM was recorded again. At this point in each trial, participants were asked to state which solution they believed they had consumed during the protocol.

Throughout each trial, the investigator ensured participants placed at least one foot on or over the line marking each end of the 20 m distance, and continually informed participants about the characteristics of each subsequent exercise phase (i.e. walk, sprint, jog, run). A cone was placed 8 m before the start line, in the centre of the runway. Participants always ended their single sprints by crossing the start line, and were instructed to stop at this cone and immediately turn and jog back across the start line to begin the jogging phase. This was to prevent premature deceleration during the sprint, ensure participants did not stop too quickly following a sprint and risk injury, and to standardise, both within- and between-participants, the distance and time between ending each sprint and beginning the jog.

This protocol is adapted from Nicholas et al (1995) and normally consists of five sets of part A followed by part B. However, adolescents normally play team games for a shorter time than adults, for example ~60 min in soccer compared to the standard adult duration of 90 min (Ekblom 1986). Therefore, in this study part A of the LIST was repeated four times (60 min), followed by part B.

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 humidity were recorded immediately before the start of the protocol, at the end of each 15 min block in part A, and at the end of part B (Hygro-thermometer). Rating of perceived exertion (RPE) was measured 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 OMNI 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 by employing 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 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 sweat loss calculation. Sweat loss was calculated from the difference between pre- and post-exercise nude BM, corrected for fluid intake and urine output. Sweat rate (SR; $L.h^{-1}$) 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. Paired t-tests compared between-trials differences in ambient temperature and humidity, fluid intake, overall mean sprint time, pre-exercise BM, BM loss and SR, and HR and GF at exhaustion. Time to exhaustion in part B, and RPE and GD at exhaustion were analysed using the Wilcoxon matched-pairs test. Mean sprint times and peak sprint times, and HR and GF during part A were analysed with a 2 way (drink x time) ANOVA, using paired t-tests with Bonferroni correction to explore significant main effects. Friedman tests were used to analyse the main effect of time during part A within each trial for RPE and GD. Wilcoxon matched-pairs tests,

with Bonferroni correction, explored significant within-trials main effects for these two measurements. Chi-square analysis assessed the frequency distribution of solution choice responses. Cohen's d effect sizes were calculated (Cohen 1992). Effect sizes were defined as small ($d \leq 0.2$), medium ($d > 0.2, < 0.8$), and large ($d \geq 0.8$; Cohen 1992). 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 14.6 ± 1.2 km.h^{-1}. Mean HR_{max} and RPE at exhaustion were 201 ± 8 b.min^{-1} and 9.0 ± 0.4, respectively.

Blinding, ambient temperature and relative humidity, and fluid intake

Of the 15 participants, seven (47%) correctly identified both solutions and eight (53%) failed to do so. Chi square analysis of the responses in the CHO trial found a non-significant deviation from the expected response frequency ($\chi^2(1) = 0.067$, $P = 0.80$). Mean ambient temperature and relative humidity during the LIST were similar between trials, at 19.6 ± 1.3 vs. 19.9 ± 1.4^{o}C ($P = 0.43$, $d = 0.27$) and 50.6 ± 15.3 vs. 51.8 ± 14.4% ($P = 0.68$, $d = 0.17$) for the CHO and PLA trials, respectively. Mean fluid intake was 739 ± 122 and 740 ± 125 ml for the CHO and PLA trials, respectively ($P = 0.33$, $d = 0.26$). In the CHO trial, this equated to a mean CHO intake of 34.7 ± 5.7 g.h^{-1}, or 0.8 g.kg^{-1} BM.

Distance covered and time to exhaustion

By design, distance covered during part A was similar between the CHO and PLA trials at 7.1 ± 0.3 and 7.2 ± 0.3 km, respectively ($P = 0.27$, $d = 0.42$). Two participants failed to complete part B in both trials, one due to gastrointestinal distress and one to temporary respiratory distress, and were excluded from all part B analyses. Time to exhaustion during part B of the LIST for both trials is in Figure 2. Participants ran for a significantly longer

time in the CHO compared to the PLA trial (5.1 ± 1.8 vs. 4.1 ± 1.6 min, $P < 0.05$, $d = 1.03$). This represents a 24.4% mean improvement in time to exhaustion. Of the 13 participants, eight ran longer in the CHO trial, four ran longer in the PLA trial, and one ran for the same duration in both trials. Distance covered in part B was significantly greater in the CHO trial (851 ± 365 vs. 694 ± 278 m, $P < 0.05$, $d = 0.88$).

(INSERT FIGURE 2 HERE)

Sprint times

The mean time of all sprints completed in each block of part A of the LIST is in Figure 3A. Sprint times throughout the LIST were faster in the CHO trial, but did not reach statistical significance ($F_{1, 12} = 0.96$, $P = 0.35$). There was also no interaction effect (drink x time, $F_{3, 36} = 0.1$, $P = 0.96$). There was, however, a main effect of time on sprint duration ($F_{1.30, 15.56} = 1.30$, $P < 0.001$). Sprint times in each block were significantly slower than the previous block ($P < 0.001$, $d = 1.92$ and 1.62 for blocks 2 and 3, respectively; $P < 0.005$, $d = 1.15$ for block 4). Overall, mean sprint times for part A of the list were 2.63 ± 0.24 and 2.66 ± 0.25 s for the CHO and PLA trials, respectively ($P = 0.38$, $d = 0.46$).

When only the participants' peak sprint time for each exercise block was analysed, there was no significant between-trials difference ($F_{1, 13} = 0.09$, $P = 0.77$; Figure 3B) and no interaction effect ($F_{3, 39} = 1.13$, $P = 0.35$). However, peak sprint times were maintained slightly better in the PLA trial, with a mean increase between bouts 1 to 4 of 0.08 ± 0.03 s compared with 0.13 ± 0.03 s in the CHO trial. There was a main effect of time on peak sprint duration ($F_{2.1, 27.3} = 2.1$, $P < 0.001$). Sprint times in block 2 were significantly slower then block 1 ($P < 0.005$, d

= 1.00), and in block 3 were significantly slower than block 2 ($P < 0.001$, $d = 1.07$). There was no significant difference between blocks 3 and 4 ($P = 0.44$, $d = 0.28$).

(INSERT FIGURE 3A & 3B HERE)

Heart rate, rating of perceived exertion and gastric measures

Mean HR during part A of the LIST and peak HR at exhaustion in part B, expressed as percentages of individual HR_{max}, are in Figure 4. Heart rate throughout part A of the LIST was greater in the CHO trial, but did not reach statistical significance ($F_{1, 12} = 3.67$, $P = 0.08$), and there was no interaction effect ($F_{1.77, 21.2} = 0.91$, $P = 0.41$). There was a main effect of time for HR in part A ($F_{1.23, 14.75} = 10.4$, $P < 0.005$). Heart rate in blocks 2 and 3 ($P < 0.001$, $d = 2.48$ and $d = 1.46$, respectively) and block 4 ($P < 0.01$, $d = 0.79$) were significantly greater than block 1. There was no significant difference between blocks 2 and 3 ($P = 0.74$, $d = 0$) or blocks 3 and 4 ($P = 0.12$, $d = 0.63$). Peak HR at exhaustion in part B was significantly greater in the CHO trial ($P < 0.05$, $d = 1.32$).

(INSERT FIGURE 4 HERE)

Rating of perceived exertion during part A of the LIST and at exhaustion in part B is in Figure 5. Values were very similar at all time points between trials, with no significant differences found. A main effect of time was present for the CHO ($\chi^2(3) = 32.5$, $P < 0.001$) and PLA ($\chi^2(3) = 40.8$, $P < 0.001$) trials. Rating of perceived exertion increased significantly with each successive exercise block ($P < 0.001$, $d = 2.23$, 1.78 and 1.36, respectively). There was no between-trials difference in RPE at exhaustion ($P = 0.71$, $d = 0$.

(INSERT FIGURE 5 HERE)

Mean GF remained quite stable throughout the protocol, with no solution ($F_{1, 14}$ = 0.17, P = 0.69), time ($F_{3, 42}$ = 1.44, P = 0.25), or interaction effects ($F_{1.8, 25.4}$ = 0.38, P = 0.67) observed. Gastric discomfort increased significantly with time in the CHO ($\chi^2(3)$ = 15.8, P < 0.005) and PLA ($\chi^2(3)$ = 8.3, P < 0.05) trials. In the CHO trial, GD in block 2 was significantly greater than block 1 (3.8 ± 2.2 vs. 2.9 ± 2.0, P < 0.01, d = 1.71), with no significant difference between blocks 2 and 3 (3.8 ± 2.2 vs. 4.0 ± 2.3, P = 0.45, d = 0.33) or 3 and 4 (4.0 ± 2.3 vs. 4.4 ± 2.5, P = 0.19, d = 0.48). In the PLA trial, the location of differences could not be determined. Gut fullness and GD at exhaustion were both greater in the CHO trial, but did not reach significance (P = 0.24, d = 0.47 and P = 0.67, d = 0.18, respectively).

Body mass loss and sweat rate

Mean pre-exercise dry nude BM was not significantly different between the CHO and PLA trials (56.8 ± 9.4 and 56.9 ± 9.6 kg, respectively, P = 0.30, d = 0.33). Mean BM loss in the CHO and PLA trials was 0.88 ± 0.24 and 0.92 ± 0.23 kg, respectively (P = 0.33, d = 0.40), equating to a mean loss of 1.54 ± 0.32 and 1.62 ± 0.37% of pre-exercise BM (P = 0.23, d = 0.48). Mean SR was 0.71 ± 0.19 and 0.72 ± 0.18 $L.h^{-1}$ in the CHO and PLA trials, respectively (P = 0.70, d = 0.13). This equates to a BM relative sweat loss of 12.43 ± 2.00 and 12.77 ± 2.76 $ml.kg^{-1}$ $BM.h^{-1}$, respectively (P = 0.51, d = 0.27).

Discussion

This is the first study to demonstrate that ingestion of a CHO-E solution prior to, and during, prolonged intermittent shuttle exercise significantly increases time to exhaustion during intermittent, high-intensity running in 12-14 year old team games players. Furthermore, CHO supplementation had no significant influence on sprint performance during prolonged intermittent shuttle exercise.

Time to exhaustion

The 24.4% improvement in time to exhaustion with CHO supplementation in the current study is a significant finding, which is further reinforced by the large ES (d = 1.03). However, it is lower than the range of improvement found in adult studies using the standard LIST (32-52%; Davis et al 2000; Nicholas et al 1995; Welsh et al 2002). This adult research has proposed the sparing of endogenous muscle glycogen via increased blood glucose uptake and oxidation and/or glycogen resynthesis during low-intensity components of the LIST as the mechanism for enhanced intermittent, high-intensity endurance capacity with CHO ingestion. The present study was not designed to identify specific mechanisms of enhancement; however, current knowledge on substrate concentration and utilisation of adolescents suggests these mechanisms may be relevant to the participants in this study. Muscle and hepatic glycogen concentrations are lower in early adolescence compared to adulthood, with concentrations increasing to adult levels throughout puberty (Aucouturier et al 2008). Additionally, pre-pubertal children are able to oxidise more exogenous CHO than adults (Timmons et al 2003; Timmons et al 2007), and adolescents may also have this ability, although exogenous oxidation rates decline throughout puberty (Timmons et al 2007). This

greater exogenous CHO use may enable greater sparing of muscle glycogen, or synthesis of glycogen during low-intensity and recovery periods, and therefore increased intermittent, high-intensity endurance capacity.

It is possible that the greater fat oxidation of young people during exercise (Timmons et al 2003) might in some way reduce the impact of ingested CHO, which may not happen in adults as they oxidise less fat at a given workload (Aucouturier et al 2008). This may have contributed to the lower percentage improvement in this compared with adult studies. Timmons et al. (2007) found similar fat oxidation rates during exercise between pre-, early-, and mid/late-pubertal boys, with a reduction in exogenous CHO oxidation in mid/late pubertal boys. The participants in this study were classified as average maturers, with a mean maturity offset of +0.51 years. This suggests that, as a group, puberty in these participants was underway (Karlberg et al 2002). This provides some support for the fat oxidation hypothesis discussed above. However, the absence of metabolic measures, coupled with the reported variance of the maturity offset equations, means the specific metabolic response of the participants in this study cannot be conclusively determined. Furthermore, four blocks of part A of the LIST were conducted in this study, compared with the five in adult work (Nicholas et al 1995; Davis et al 2000). While this was appropriate due to the shorter duration of youth team sports (Ekblom 1986), and helps to explain the shorter part A distance compared with adult work (Nicholas et al 1995), it may have led to a lesser depletion of glycogen stores in both trials. This could also have contributed to the smaller effect of CHO in the current study. However, this cannot be confirmed without assessing resting muscle glycogen concentration, which may be lower in young participants than adults, and in which case could negate the glycogen sparing effect of a shorter exercise protocol. Future work should attempt to address these hypotheses, which will require overcoming ethical issues

concerning metabolic measurement in adolescents, namely muscle biopsies and cannulation, and the potential insensitivity of some non-invasive measures of metabolism, such as expired gas analysis (Ali et al 2007).

Sprint Duration

The lack of influence of CHO supplementation on mean sprint duration throughout the LIST in this study is in line with previous work (Davis et al 2000; Nicholas et al 1995; Nicholas et al 1999). It is unsurprising that CHO intake had no influence on sprint performance, as it is phosphocreatine (PCr) availability and its rate of resynthesis, rather than CHO availability that determines short-duration sprint performance (Greenhaff et al 1994). Furthermore, PCr resynthesis rates may be faster in young people (Taylor et al 1997), which would further explain the lack of effect of CHO on sprint performance in the current study.

Participants in the present study completed ~35 sprints, each separated by ~93 s of walking, jogging and running. It has been shown that 15 m sprints separated by 30 s passive recovery can be repeated without decreases in performance (Balsom et al 1992). However, time between sprints in this study was not spent resting passively. In this situation, the increased O_2 demand of the activity between sprints may create a competition for O_2 between PCr resynthesis and other processes such as lactate oxidation, oxymyoglobin replenishment, and the O_2 demand of the activity (Spencer et al 2006), thereby reducing PCr resynthesis. Supporting this, reduced PPO during repeated sprints with active vs. passive recovery has been demonstrated in young participants (mean age 15.9 years; Thevenet et al 2007). This incomplete PCr resynthesis may explain why sprint times progressively slowed throughout the protocol, in line with some previous work (Ali et al 2007; Morris et al 2003).

Furthermore, the standardised between-trials physiological demand of the protocol, and the lack of influence of CHO on PCr kinetics, could explain the similar between-trials increase.

Interestingly, in the current study the mean increase in sprint time from the first to the last block in part A of 0.20 and 0.19 s in the CHO and PLA trials, respectively, is notably greater than that recorded in previous adult work (0.08 s for both trials; Ali et al 2007; Morris et al 2003). It appears the young participants in this study did not display a greater fatigue resistance than adults during sprinting in the LIST protocol, as may have been expected, and in fact showed an inferior ability to maintain sprint performance, supported by the large ES for the differences in sprint time between each exercise block. This interesting finding warrants further investigation.

This is the first study to investigate peak sprint time throughout the LIST. A similar response was observed to that of the mean of all sprints, namely no significant between-trials difference and a progressive increase in peak sprint duration over time. These findings lend further support to the overriding view that CHO ingestion during prolonged intermittent exercise does not have a significant impact on repeated short duration sprint performance.

Heart rate and rating of perceived exertion

The similar between-trials HR and RPE responses during part A of the LIST in the current study are in agreement with most previous research (Ali et al 2007; Morris et al 2003; Nicholas et al 1995; Nicholas et al 1999; Welsh et al 2002). This confirms that participants encountered a similar stress during both trials. The significant influence of time on HR in this study is again in line with some previous adult work (Ali et al 2007; Morris et al 2003).

Furthermore, the non-significant trend for a higher HR in the CHO trial has been observed in adult participants beginning the LIST in both glycogen depleted and supplemented states (Ali et al 2007; Foskett et al 2008). It appears that this trend cannot be explained by greater levels of dehydration or a greater work intensity in the CHO trial. It would be interesting to see if this is a consistent finding in future work using young participants.

The progressive increase in RPE with time may be due to an incomplete recovery, and therefore a cumulative fatigue, from the previous exercise bout(s). This is partially supported by the observation of a progressive increase in [BLa] throughout the LIST in some adult research (Nicholas et al 1995; Nicholas et al 1999), which may contribute to this progressive increase in RPE (Noakes et al 2005). However, this needs to be quantified in adolescent participants.

The significantly greater peak HR at exhaustion in the CHO trial in the current study has not been observed in previous work. Nicholas et al (1995) recorded a non-significant 1.1% greater peak HR at exhaustion in the CHO trial, compared to the 2.6% difference in this study. It is possible that the ergogenic effect of the CHO enabled participants to continue working to a higher intensity via better maintenance of muscle metabolism, whereas in the PLA trial less glycogen availability could have resulted in the inability of participants to maintain the required work output, and therefore reach exhaustion, at a lower relative intensity. This would still represent a maximal effort for both trials and support the mechanisms of action with CHO ingestion discussed above; however, muscle metabolic measurements would be needed to confirm this hypothesis.

Alternatively, the greater performance in the CHO trial may relate to the influence of CHO on perceptual responses to exercise. It has recently been demonstrated that CHO ingestion can significantly attenuate RPE during a standardised 2-h intermittent cycling protocol (Utter et al 2007), and Backhouse et al (2007) suggest this could also occur during the LIST. It appears that CHO supplementation may facilitate a more favourable perception of the demands of the exercise bout, resulting in participants recording a lower RPE score at a given exercise intensity (Backhouse et al 2007; Utter et al 2007), or achieving a higher intensity for a given RPE. This is partly supported by observation that RPE at exhaustion in part B in the current study was the same between-trials, despite a significantly higher HR in the CHO trial.

Fluid and carbohydrate intake

Mean fluid and CHO intake in this study was lower than that of previous adult research due to the lower mean BM of our participants, and the five drink periods in this study compared with six in adult studies. As this is the first study of its kind, it was decided to keep the CHO concentration and ingestion volumes in line with previous research in order to generate data comparable to existing findings. Also, the lack of information regarding the effects of CHO ingestion in adolescents during this form of exercise, in addition to the absence of guidelines for CHO ingestion during exercise in this age group, suggests it would have been inappropriate to use CHO concentrations notably lower or greater than the commonly used, and widely commercially available, 6% solution. Based on the findings of this study, the impact of variations in CHO intake during the LIST in adolescents requires further investigation.

Gut fullness and gastric discomfort

None of the previous research investigating CHO solution ingestion during the LIST measured GF or GD. Research has demonstrated a negative relationship between ingested CHO concentrations of 2.5 – 17% and the rate of gastric emptying (Maughan and Leiper 1999). However, the GF response, coupled with the SR and BM loss data, in this study suggests that regular ingestion of a 6% CHO-E solution does not slow gastric emptying to the extent where fluid availability, and hence thermoregulation, become impaired. The time to exhaustion data also suggests that sufficient CHO was absorbed from the intestine into the systemic circulation to enhance endurance capacity. This leaves the question of what caused the progressive increase in GD in both trials. As it appears to be a CHO independent cause, it may be speculated that the young participants, when asked the question 'on a scale of 1-10, how upset does your stomach feel?', may have found it difficult to distinguish between gastric discomfort and discomfort of other localised origins, for example the diaphragm and associated respiratory muscles. This may help to explain the dissociation between the GF and GD data. From this data, it appears that 12-14 year olds are generally able to tolerate well a 6% CHO-E solution during prolonged high-intensity, intermittent exercise.

Body mass loss and sweat rate

The non-significant between-trials difference in BM loss in this study (1.54 and 1.62% for the CHO and PLA trials, respectively) is in line with previous work (Ali et al 2007; Morris et al 2003; Nicholas et al 1995; Nicholas et al 1999), and suggests a similar degree of thermal stress during each trial. No prior research has assessed SR during the LIST in thermoneutral

conditions. However, the similar mean SR between trials in the current study mirrors the BM loss data, and infers a comparable between-trials thermoregulatory ability.

Gender differences

Due to the low number of female participants (n=5) in the current study, it was not feasible to conduct statistical analyses of gender differences between measurements. Such analyses would have been lacking appropriate statistical power. Future work may consider recruiting more female participants and performing such comparisons.

Blinding

In a study using two perfectly blinded solutions, it could be expected that 50% of participants would correctly identify both solutions by chance alone (Boutron et al 2005). Therefore, the blinding procedures in this study appeared successful. However, it may not be appropriate to evaluate the success of blinding procedures simply by comparing them to chance. People who experience positive outcomes may guess that they are in the treatment group and those who experience satisfactory or unsatisfactory outcomes may presume they are in the PLA group (Boutron et al 2005). In the context of this study, if participants felt more 'energised' during one trial, it may have prompted them to choose this as the treatment, despite being unable to distinguish between solutions by taste, smell, colour or texture. Anecdotally, this did appear to occur in some of the participants in this study. Obviously, this method of solution choice cannot be blinded.

Preliminary tests: V_{peak} and HR_{max}

Combined mean V_{peak} values of 10.8 km.h^{-1} have been reported in international samples of males and females aged 12-14 years during incremental shuttle running to exhaustion (Olds et al 2006; Sandercock et al 2008). These values are considerably lower than the mean V_{peak} of 14.6 km.h^{-1} in the present study, suggesting our participants were of a notably higher training status than international population means. However, the protocols of Olds et al (2006) and Sandercock et al (2008) were conducted indoors and outdoors on different surfaces, with participants completing the protocol in groups. In the current study, the protocol was conducted individually, indoors on a motorised treadmill. Additionally, the criteria for determining V_{peak} were different in the present study compared to the other two studies. This may have contributed to the different V_{peak} values, and highlights the sensitivity of V_{peak} measurement to the protocol used.

Typical HR_{max} during incremental treadmill running to exhaustion in adolescents is reported to be 200 ± 7 b.min^{-1} (Armstrong 2007). The mean HR_{max} of 201 ± 8 b.min^{-1} recorded in our study, coupled with a mean RPE (0-10 scale) score of 9 ± 0.4 and consistent observation of subjective markers of fatigue (facial flushing, unsteady gait, heavy sweating, hyperpnoea), provides strong evidence that a maximal effort was generated by our participants.

Conclusion

This study is the first to demonstrate that ingestion of a 6% CHO-E solution prior to and during prolonged intermittent exercise significantly improves the intermittent, high-intensity endurance capacity of 12-14 year old team games players. Furthermore, it is the first to show

that CHO ingestion does not significantly alter sprint performance during prolonged intermittent work in these participants. Finally, the physiological response of 12-14 year old participants to this form of exercise appears similar to that of adults.

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Conflict of Interest

The authors declare they have no conflict of interest regarding this study.

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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Figure captions

Fig 1 Schematic of the experimental protocol (adapted from Nicholas et al 1995)

Fig 2 Time to exhaustion (min) during part B of the LIST in the CHO and PLA trial.
* significantly greater than the PLA trial, $P < 0.05$ (n=13).

Fig 3A Mean sprint duration (s) during part A of the LIST for both trials. ** significantly greater than previous block ($P < 0.001$), # significantly greater than previous block ($P < 0.005$) (n=14).

Fig 3B Mean peak sprint duration (s) during part A of the LIST for both trials. # significantly greater than previous block ($P < 0.005$), ** significantly greater than previous block ($P < 0.001$) (n=14).

Fig 4 Mean HR (% HR_{max}) during part A of the LIST (*n*=14), and peak HR at exhaustion in part B (*n*=13) for both trials. ** significantly greater than block 1 ($P < 0.001$), *** significantly greater than block 1 ($P < 0.01$), * significantly greater than the PLA trial ($P < 0.05$).

Fig 5 Mean rating of perceived exertion scores during part A of the LIST (*n*=15), and at exhaustion in part B (*n*=13) for both trials. ** significantly greater than previous block ($P < 0.001$).