European Journal of Applied Physiology (2019) 119:1019–1027
https://doi.org/10.1007/s00421-019-04091-z

ORIGINAL ARTICLE

Carbohydrate consumption and variable-intensity exercise responses in boys and men

Lisa M. Guth[1] · Michael P. Rogowski[1] · Justin P. Guilkey[1,2] · Anthony D. Mahon[1]

Received: 20 June 2018 / Accepted: 31 January 2019 / Published online: 9 February 2019

Abstract

Purpose The effect of carbohydrate (CHO) supplementation on physiological and perceptual responses to steady-state exercise has been studied in children. However, little is known about these responses to variable-intensity exercise (VIE) and how these responses might differ from adults. This study examined the physiological and perceptual effects of CHO on VIE in boys and men.

Methods Eight boys (11.1 ± 0.9 years) and 11 men (23.8 ± 2.1 years) consumed CHO or a placebo (PL) beverage before and throughout VIE (three 12-min cycling bouts with intensity varying every 20–30 s between 25, 50, 75, and 125% peak work rate). Pulmonary gas exchange was assessed during the second 12-min bout. RPE was assessed twice per bout.

Results In CHO, blood glucose increased and then decreased more from pre-exercise to 12 min and was higher in this trial at the end of exercise in men versus boys. In boys, blood glucose in CHO was higher at 24 and 36 min of exercise than in PL. RER during the CHO trial was higher in both groups; the other physiological responses were unaffected by CHO. All RPE measures (whole body, legs and chest) increased over time, but were not different between groups or trials.

Conclusion Blood glucose patterns during VIE were differentially affected by CHO in boys and men, but most physiological and perceptual responses to VIE were unaffected by CHO in either group. Knowledge of the underlying mechanisms of glucose regulation and effects on physical performance during this type of exercise in children is warranted.

Keywords Blood glucose · Metabolism · Child–adult difference · Cycle ergometry

Abbreviations

ANOVA	Analysis of variance
CHO	Carbohydrate
HR	Heart rate
LIST	Loughborough Intermittent Shuttle Test
PL	Placebo
RER	Respiratory exchange ratio
RPE	Rating of perceived exertion
VIE	Variable-intensity exercise
VO_2	Oxygen uptake

Communicated by Philip D. Chilibeck.

✉ Anthony D. Mahon
tmahon@bsu.edu

[1] Human Performance Laboratory, Ball State University, Muncie, IN 47306, USA

[2] Present Address: Department of Kinesiology, Coastal Carolina University, Conway, SC 29528-6054, USA

Introduction

The metabolic and perceptual responses during prolonged (≥ 30 min), steady-state, aerobic exercise have been studied in children (Cheatham et al. 2000; Martinez and Haymes 1992; Timmons et al. 2003, 2007a). Compared to adults, children typically rely on a higher percentage of fat and lower percentage of carbohydrate (CHO) at the same relative intensity during this type of exercise (Aucouturier et al. 2008; Mahon and Timmons 2014; Martinez and Haymes 1992; Riddell 2008; Timmons et al. 2003). It has been suggested that lower muscle glycogen concentration and an under-developed glycolytic energy system are the primary reasons for these differences (Eriksson 1972; Eriksson and Saltin 1974). There is evidence that blood glucose concentration in children may decline at the onset of aerobic exercise and then return to pre-exercise levels (Delamarche et al. 1992, 1994). However, it has also been shown that blood glucose may decline and remain depressed for up to 30 min (Foricher et al. 2003) or not change at all at the onset of exercise (Oseid and Hermansen 1971). From a perceptual

standpoint, the rating of perceived exertion (RPE) has been shown to increase more over time, during 40 min at an intensity corresponding to the ventilatory threshold, in boys compared to men (Cheatham et al. 2000).

Studies examining the effect of exogenous CHO before and during prolonged steady-state exercise in children have shown that the respiratory exchange ratio (RER) increases, indicating increased reliance on CHO and decreased reliance on fat (Riddell et al. 2000, 2001; Timmons et al. 2007a). The intensity of the exercise bouts in these studies ranged from 55 to 70% of VO_{2max}, and duration ranged from 60 to 120 min. Moreover, Timmons et al. (2003) showed that boys used ~ 50% (21.8% vs. 14.6%) more exogenous CHO during 60 min of exercise at 65% of VO_{2max} compared to men. The effects of ingesting exogenous CHO on RPE during exercise also have been studied. Timmons and Bar-Or (2003) reported that there was no trial [CHO versus placebo (PL)] difference in overall RPE among boys and men, but that RPE was significantly higher from 15 to 60 min in boys when the CHO and PL trials were combined.

Examining physiological responses to variable-intensity exercise (VIE) offers an alternative approach to steady-state exercise paradigms and might more closely parallel the nature of sport performance in the field. To this end, two studies by Phillips et al. (2010, 2012) examined the effects of exogenous CHO versus PL administration on RPE, heart rate (HR), and performance in adolescents (mean ages 12.7 and 13.5 years) performing the Loughborough Intermittent Shuttle Test (LIST)—a form of VIE. In these studies, the LIST was performed in 4 × 15 min bouts of exercise followed by a performance shuttle run to exhaustion. In both studies, exogenous CHO improved performance, but RPE and HR during the LIST were unaffected by CHO consumption. Although these studies indicate the benefits of exogenous CHO during VIE on performance in this population, the effects of exogenous CHO on metabolism and blood glucose concentration are largely unknown. In addition, there do not appear to be reports in the literature with respect to better understanding the influence of exogenous CHO in children on differentiated RPE (chest and legs versus overall RPE). Assessing the differentiated RPE provides more information on the specific involvement of the perceptual cues arising from the cardiorespiratory strain (chest RPE) and local muscular strain (leg RPE) than would be obtained by assessing the overall RPE alone (Noble and Robertson 1996).

Therefore, the aim of this study was to examine the effect of an exogenous CHO drink before and during VIE on the physiological responses during VIE in pre- and early-pubertal boys and men. In addition, the effects of exogenous CHO on overall and differentiated RPE were examined. Studies on child–adult differences with regard to exercise and CHO supplementation have been primarily limited to prolonged, steady-state exercise at a constant metabolic state. VIE results in constant fluctuation in the metabolic demand of exercise and is typical of many childhood sporting activities (e.g., soccer, basketball, and ice hockey). Knowledge of the child's response to supplemental CHO during this type of physical exertion will advance the literature and be informative with regard to developing optimal CHO replenishment strategies to optimize the performance for children during these activities.

Methods

Fifteen boys, ages 10–12 years (pubertal stages 1 and 2), and 16 men, ages 18–30 years, volunteered for this study. However, only 8 boys and 11 men completed both trials (see "Results" for details). Boys, with the help of a parent, self-selected their pubertal stage using the Tanner pubic hair maturity criteria (Tanner 1962). Subjects were healthy and not taking medications affecting the physiological responses to exercise. Participation was limited to individuals with a peak VO_2 between 35 and 55 mL kg^{-1} min^{-1}, to minimize the effect of aerobic fitness on the outcomes. This study was approved by the university's Institutional Review Board. Written informed consent for adults and written parental permission and child assent were obtained prior to testing.

Each subject reported to the laboratory on 3 separate days. On the first visit, the subjects read instructions regarding the use of the OMNI 0–10 RPE scale (Robertson et al. 2000) and answered a set of questions to verify understanding followed by the measurement of height and mass. Subjects then practiced cycling with a mouthpiece breathing valve and nose clip at two different intensities (25 and 50 W) for 2.5 min at each workload to become familiar with the exercise testing. After a 5-min rest period, a graded exercise test to peak exertion was performed on the cycle ergometer. For children, the protocol began at 25 or 50 W and increased by 25 W every 2 min until a near-peak effort; thereafter, work rate increased by 12–13 W per minute until volitional exhaustion. For adults, the protocol began at 50 or 100 W and increased by 50 W every 2 min until a near-peak effort; thereafter, work rate increased by 25 W per minute until volitional exhaustion. The participants were instructed to maintain a pedal rate between 70 and 90 rpm. HR and RPE_{body} were recorded at the end of each stage. The attainment of a peak effort required achievement of at least two of the following criteria: (1) failure to maintain a pedal rate > 50 rpm, (2) respiratory exchange ratio (RER) ≥ 1.00 (children) or ≥ 1.10 (adults), (3) peak HR ≥ 95% of age-predicted maximum (208 − 0.7 × age), and (4) RPE ≥ 8.

A rest period of 15 min was allowed after the graded exercise test, followed by a VIE familiarization session on the cycle ergometer. The protocol involved six 2-min cycles consisting of exercise at percentages of peak work rate in the

following order: 20 s at 25%; 30 s at 50%, 20 s at 125%, 30 s at 25%, and 20 s at 75%. HR and RPE_{body} were recorded at the end of each 2-min cycle.

On the night before the second and third visits, all subjects recorded and replicated their diet each for each trial. On the morning of each experimental trial, they consumed a controlled breakfast (Carnation® No Sugar Added Instant Breakfast Drink prepared with a self-selected milk type) 1 h before arriving to the laboratory. Children consumed one serving and adults two servings of the breakfast drink. This served to standardize the acute effect of diet on the response to exercise; all subjects confirmed compliance. Before exercise, subjects rested in a seated manner for 30 min. After this, a 5-min warm-up at 25% of peak work rate on the cycle ergometer was performed after which the VIE protocol commenced. The VIE protocol consisted of three 12-min sets of 6 × 2-min cycles. Each 2-min cycle consisted of exercise at percentages of peak work rate as follows: 20 s at 25%, 30 s at 50%, 20 s at 125%, 30 s at 25%, and 20 s at 75%. A 3-min rest was given after the first and second 12-min sets. HR, RPE_{body}, RPE_{chest}, and RPE_{legs} were recorded every 6 min. Participants were instructed to maintain a pedal rate between 70 and 90 rpm. Prior to exercise the subjects were oriented to applying the RPE selection for the whole body and for the chest and legs.

The protocol for the second and third visits is shown in Fig. 1. CHO (Gatorade 6% CHO) and PL (Propel Fitness Water with additional food coloring and grape Kool-Aid) drinks were administered upon arrival to the laboratory, after 15 min of seated rest, at the end of seated rest, and during the 3-min rests between 12-min sets of exercise. The drink volume was 2.5 mL kg^{-1} body weight; the CHO drink had a 6% CHO content. This drink regimen (volume and timing) was modeled after Riddell et al. (2001) and the order was counterbalanced and administered in a double-blind manner. Fingertip capillary blood samples were taken for the assessment of glucose and lactate concentrations. Samples were obtained upon arrival to the laboratory, after 30 min of rest, during each 3-min rest period between exercise bouts, and immediately following the last exercise bout. Pulmonary gas exchange was assessed during the second 12-min set of exercise only. Measurements of pulmonary gas exchange were limited to one 12-min bout due to the intense nature of the protocol. Although the effects of CHO consumption may have been more pronounced in the third set, it was deemed that gas exchange measurement in the second set would be more tolerable to the participants. Moreover, the gas exchange protocol follows the procedures used in a prior study involving children (Mahon et al. 2010).

Height and weight were measured using a wall-mounted stadiometer (Seca 222, Hanover, MD) and calibrated digital scale (Toledo 1D1 Multirange Scale, Worthington, OH), respectively, during the first visit. HR was recorded with a Polar Monitor® (Polar USA, Inc., Stamford, CT). Exercise was performed on an electromagnetically braked cycle ergometer (Lode Excalibur Sport, Groningen, Netherlands). Pulmonary gas exchange measurements were collected using mouthpiece breathing valve (models 2600 and 2700, Hans Rudolph, Kansas City, MO) and nose clip. Inspired volume was measured by a Parkinson–Cowan dry-gas meter (Rayfield Equipment, Waitsfield, VT). Expired air was sampled from a mixing chamber and drying line (Perma Pure, Inc,

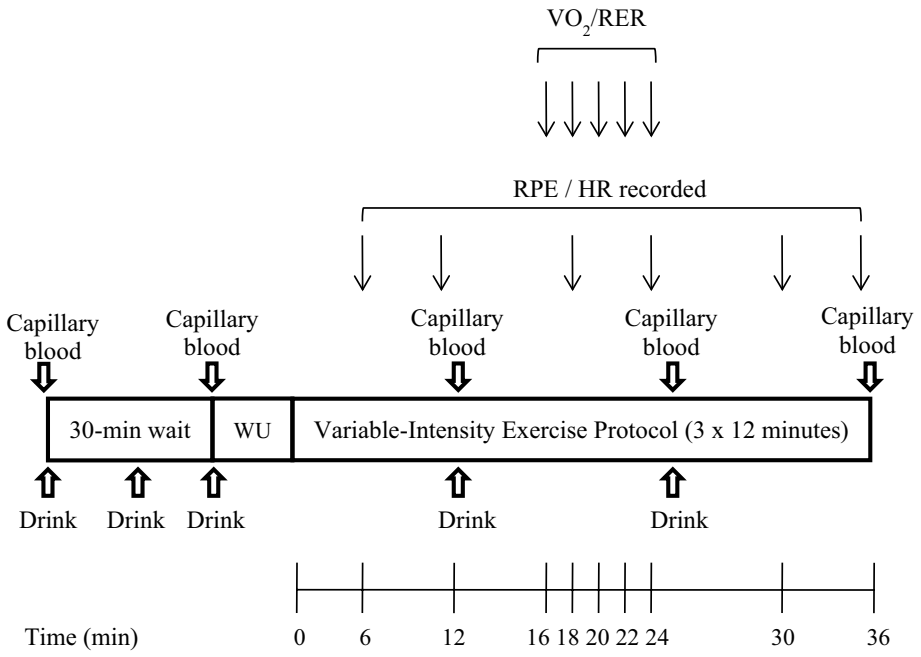

Fig. 1 Schematic of the experimental research protocol. *VO_2* oxygen consumption, *RER* respiratory exchange ratio, *WU* 5-min warm-up, *RPE* rating of perceived exertion (OMNI 0–10 scale), *HR* heart rate

Toms River, NJ), and analyzed for O_2 and CO_2 concentrations using calibrated S-3A/I and a CD 3A analyzers (Applied Electrochemistry, Inc., Pittsburgh, PA), respectively. The analyzers and dry-gas meter were connected to a computer where a metabolic software program calculated and recorded VO_2 and RER.

Blood glucose concentrations were analyzed using an automated analyzer (BD Logic, Waltham, MA). Blood samples for lactate determination were drawn into a two 30-µL capillary tubes, immediately lysed in 100 µL of 8% perchloric acid, and frozen at − 20 °C for later analysis. Lactate concentrations were measured using a Beckman Coulter Inc. Spectrophotometer (DU 530 Life Science UV/Vis, Fullerton, CA) according to the standardized procedures (Passonneau and Lowry 1993).

Peak work rate was calculated as the sum of the last fully completed work rate during the graded exercise test plus a portion of the final stage in progress. The final-stage increment was pro-rated based on the percentage of the stage completed before volitional exhaustion. Values obtained during the graded exercise were recorded as follows: the highest 1-min average was used for peak RER and VO_2; the highest 30-s average HR was recorded as the peak HR. During the second 12-min set of each VIE protocol, VO_2 and RER values were averaged for each 2-min cycle. The gas exchange data from the first 2-min cycle were excluded from analysis.

Data are reported as means ± SD. Anthropometric and peak exercise responses were analyzed by an independent two-tailed *t* test. Physiological and perceptual responses to VIE were analyzed using a time × trial × group repeated-measures ANOVA. Bonferroni post hoc testing was performed to determine specific differences where significant time or interaction effects were observed. For six of the analyses (VO_2 per kg, RPE_{legs}, glucose, lactate, RER, and HR), there were violations of the homogeneity of variance assumption. To account for this, three men were randomly deleted and these analyses were re-run with equal sample sizes as a means to make the tests conditionally robust to these violations. (Stevens 2002). As these outcomes were identical with respect to all main effects and all interactions, the results reported are based on the full group of boys ($n = 8$) and men ($n = 11$). Statistical significance was accepted at $p < 0.05$.

Results

Of the 15 boys and 16 men recruited for this study, 19 subjects (8 boys and 11 men) successfully completed all trials. Four boys and two men were outside the peak VO_2 range. Two boys and two men did not complete one or both trials due to gastric distress and/or fatigue; and one boy withdrew from the study for unknown reasons. Finally, the data for one man were excluded due to an error in coding his drink order. Thus, 11 men and 8 boys completed all trials and were included in the analyses. The age, height, and mass were 23.8 ± 2.1 years, 171.8 ± 8.2 cm, and 77.0 ± 11.0 kg, and 11.1 ± 0.9 years, 145.3 ± 4.9 cm, and 40.6 ± 7.7 kg for the men and boys, respectively. Six boys were pubertal stage 1, and two boys were pubertal stage 2.

Table 1 Peak exercise responses in men and boys ($M \pm SD$)

Variable	Men	Boys
VO_2 ($L \cdot min^{-1}$)	3.45 ± 0.57	1.82 ± 0.13*
VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	44.8 ± 4.4	45.7 ± 5.5
RER	1.23 ± 0.06	1.13 ± 0.04*
HR (bpm)	189 ± 11	200 ± 5*
RPE	9.7 ± 0.6	8.9 ± 1.2

*Significantly different from men

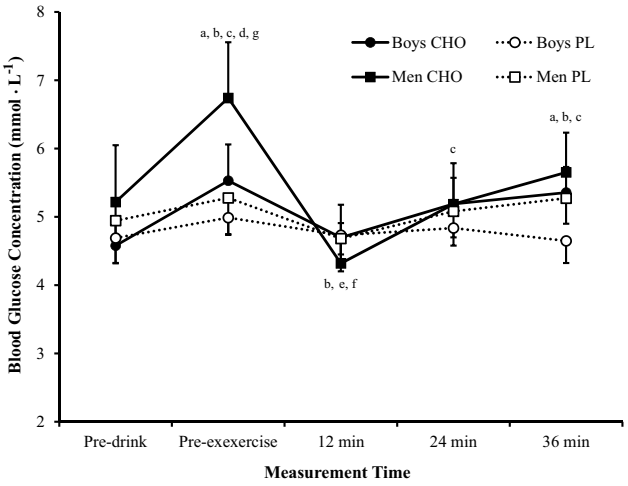

Fig. 2 Blood glucose concentration in men and boys during VIE ($M \pm SD$). Group × trial × time effect statistically significant; [a]men > boys at pre-exercise in CHO and at 36 min in PL; [b]men CHO different than PL at the same time; [c]boys CHO different than PL at same time; [d]men CHO pre-exercise > pre-drink, 12 min, 24 min, and 36 min; [e]men CHO 12 min < pre-drink, 24 min, and 36 min; [f]men PL 12 min < pre-exercise, 24 min and 36 min; and [g]boys CHO pre-exercise > pre-drink

The peak exercise responses are shown in Table 1. All subjects attained at least two of the four criteria for a peak effort. Peak VO_2 in $L \cdot min^{-1}$ and RER were higher in the men ($p < 0.05$). However, there was no difference in peak VO_2 relative to body mass. HR at peak exercise was lower ($p < 0.05$) in the men, whereas RPE_{body} was similar between groups. Peak work rate was 295 ± 49 W for the men and 141 ± 12 W for the boys ($p < 0.05$).

There was a time-by-trial-by-group interaction effect for blood glucose (Fig. 2). In CHO at pre-exercise, and in PL at 36 min, men had higher ($p < 0.05$) blood glucose levels

than boys. In men, blood glucose concentration differed ($p < 0.05$) between trials pre-exercise and at 12 and 36 min. In boys, blood glucose concentration pre-exercise and at 24 and 36 min were higher ($p < 0.05$) in CHO versus PL. In men, blood glucose in CHO was higher ($p < 0.05$) pre-exercise compared to all time points and the glucose concentration at 12 min was lower ($p < 0.05$) than at pre-drink, 24 and 36 min. In men during PL, glucose concentrations pre-exercise and at 24 and 36 min were higher ($p < 0.05$) than at 12 min. In boys during CHO, the pre-exercise blood glucose level was higher ($p < 0.05$) than the pre-drink concentration. Blood glucose levels were similar across time during PL in the boys.

During VIE, HR ranged from 148 ± 10 bpm to 170 ± 10 bpm and 148 ± 10 bpm to 171 ± 12 bpm in men in the CHO and PL trials, respectively. In boys, HR ranged from 157 ± 10 bpm to 178 ± 5 bpm in the CHO trial and from 156 ± 8 bpm to 179 ± 7 bpm in the PL trial. The higher HR in boys approached, but did not achieve, statistical significance ($p = 0.055$). The increase in HR over time was significant; the trial main effect and all interactions were not significant.

Pulmonary gas exchange responses during VIE are shown in Table 2. Time main effects for VO_2 relative to body mass and % peak VO_2 were significant; values at 16 and 18 min were lower ($p < 0.05$) than the subsequent values which did not differ from one another. No other main effects or interactions for these two variables were apparent. There were significant main effects for group, trial, and time for RER, but all interactions were not significant. RER was lower ($p < 0.05$) in boys than men, higher ($p < 0.05$) in CHO versus PL, and increased ($p < 0.05$) over time with the RER at 16 min lower than all the subsequent RER measurements.

Blood lactate (mmol L^{-1}) responses are presented in Fig. 3. Blood samples were obtained in only 9 men, but in all 8 boys. There was a significant group by trial-by-time interaction. In both trials, men maintained higher ($p < 0.05$) blood lactate concentrations during VIE than did boys. In men during both CHO and PL and in boys during CHO, blood lactate concentrations at 12, 24, and 36 min were higher ($p < 0.05$) than measures obtained pre-drink and

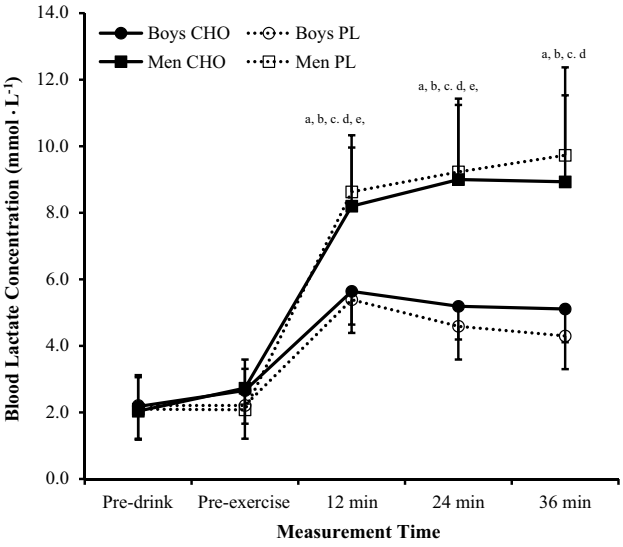

Fig. 3 Blood lactate concentration in men ($n = 9$) and boys during VIE ($M \pm SD$). Group × trial × time effect statistically significant; [a]men > boys in CHO and PL; [b]both groups CHO at 12 min, 24 min, and 36 min > pre-drink and pre-exercise; [c]men PL at 12 min, 24 min and 36 min > pre-drink and pre-exercise; [d]boys PL at 12 min, 24 min, and 36 min > pre-drink; and, [e]Boys PL at 12 min and 24 min > pre-exercise

Table 2 Pulmonary gas exchange responses during VIE in men and boys ($M \pm SD$)

Group	Time (min)	PL			CHO		
		VO_2 (mL·kg^{-1}·min^{-1})**	% Peak VO_2**	RER*, **, ***	VO_2 (mL·kg^{-1}·min^{-1})	% Peak VO_2	RER
Men	16	31.3 ± 2.1	70.0 ± 3.8	0.96 ± 0.03	30.8 ± 2.7	68.9 ± 4.3	0.98 ± 0.02
	18	31.8 ± 1.9	71.3 ± 4.2	0.98 ± 0.02	31.2 ± 2.7	69.9 ± 4.2	1.00 ± 0.02
	20	32.2 ± 2.3	72.1 ± 3.8	0.98 ± 0.03	32.0 ± 2.8	71.7 ± 4.3	1.00 ± 0.02
	22	32.4 ± 2.4	72.6 ± 3.8	0.99 ± 0.03	32.0 ± 2.8	71.6 ± 4.5	1.00 ± 0.03
	24	32.7 ± 2.4	73.3 ± 3.7	0.98 ± 0.03	32.2 ± 3.0	72.0 ± 4.5	1.00 ± 0.02
Boys	16	32.5 ± 3.2	71.9 ± 3.0	0.92 ± 0.04	32.5 ± 1.5	71.5 ± 4.3	0.94 ± 0.04
	18	31.9 ± 3.5	70.5 ± 4.6	0.96 ± 0.03	32.8 ± 1.8	72.1 ± 3.8	0.97 ± 0.04
	20	32.5 ± 3.0	71.9 ± 2.9	0.94 ± 0.03	33.2 ± 1.7	73.0 ± 4.6	0.97 ± 0.03
	22	32.7 ± 3.0	72.5 ± 4.0	0.94 ± 0.03	33.1 ± 1.3	72.9 ± 4.6	0.97 ± 0.02
	24	33.3 ± 2.8	73.7 ± 4.2	0.95 ± 0.03	33.1 ± 1.8	72.9 ± 4.1	0.97 ± 0.03

VO_2 and % Peak VO_2: **significant main effect for time only (16 min and 18 min < 20 min = 22 min = 24 min)

RER: *significant main effect for group (men > boys); **significant main effect for time (16 min < 18 min = 20 min = 22 min = 24 min); and ***significant main effect for trial (CHO > PL)

pre-exercise. In boys, blood lactate concentration during exercise in PL was higher ($p < 0.05$) during VIE compared to pre-drink, and lactate measures at 12 and 24 min were higher ($p < 0.05$) than pre-exercise.

There were no main effects for group or trial and no interactions for any of the RPE comparisons, but there was a significant main effect for time for RPE_{body}, RPE_{chest}, and RPE_{legs} (Table 3). All RPE measures increased ($p < 0.05$) from 6 to 12, 18 to 24, and 30 to 36 min.

Discussion

There is a paucity of research with respect to the comparison of physiological and perceptual responses to CHO supplementation in children and adults performing VIE. This study investigated the physiological and perceptual responses during this type of exercise in a group of boys and young men. The overall general demand of this type of exercise was ~ 70% of peak VO_2 based on the pulmonary gas exchange measurements during the middle bout of the VIE. There were group- and trial-specific variations with respect to blood glucose concentrations, RER, and blood lactate concentrations. HR tended to be higher in the boys, but the group difference was not statistically significant ($p = 0.055$). There were no differences between groups or trial for any of the RPE measurements, but all RPE measures increased over time.

Within the CHO trial, there were marked differences in the blood glucose responses between groups. In this trial, blood glucose concentration increased from pre-drink to pre-exercise, but the increase was significantly greater in men than in boys. The pre-exercise blood glucose level in the men was also significantly greater than all the other blood glucose measures in this group during the CHO trial; this response was not apparent in the boys. Similarly, there were differences in the decrease in blood glucose following the initial rise. Following the increase in blood glucose in men, a sharp decrease ensued after the first exercise bout (12 min). Both the increase and subsequent decrease in blood glucose concentration in the boys over this time period (pre-drink to 12 min) were attenuated. The difference in blood glucose responses between groups could be due to several factors. First, there were differences in the amount of glucose consumed between the groups. Although drink volume and glucose concentration were scaled to mass, the absolute amount of glucose consumed by the men in this trial was greater than the consumption by the boys. This may have triggered a greater insulin response in men, coupled with contraction-mediated glucose uptake, resulting in the subsequent decline in blood glucose following the first 12 min of exercise. Second, men would have activated greater absolute muscle mass during exercise and this may have affected the rate of clearance hastening the rate of decline in blood glucose at the end of the first bout of exercise. Third, there may be differences in the hormonal factors that regulate blood glucose concentration during exercise and in response to CHO, but, as noted by Riddell (2008), more studies involving children are needed. Finally, the rate of gastric emptying may have differed between groups. Evidence from a study on milk consumption indicated that gastric emptying was slower in children than adults (Maes et al. 1995).

In the boys, post-exercise blood glucose concentration differed between trials, but neither value varied significantly from the initial blood glucose concentration, so it is difficult to ascertain which condition (if either) is more favorable. However, it is worth noting that blood glucose in PL was closer to being in the hypoglycemic range than the value

Table 3 Body, leg, and chest RPE responses during VIE in men and boys ($M \pm SD$)

Group	Time (min)	PL			CHO		
		RPE_{body}**	RPE_{legs}**	RPE_{chest}**	RPE_{body}	RPE_{legs}	RPE_{chest}
Men	6	3.1 ± 1.3	4.3 ± 1.4	2.2 ± 1.3	2.5 ± 1.2	3.5 ± 1.4	1.9 ± 1.4
	12	4.1 ± 1.2	5.1 ± 1.4	2.9 ± 1.5	3.5 ± 1.6	4.6 ± 1.4	2.9 ± 1.8
	18	4.6 ± 1.4	5.6 ± 1.0	3.6 ± 1.5	4.3 ± 1.6	5.4 ± 1.2	3.6 ± 1.9
	24	5.5 ± 1.2	6.7 ± 1.0	4.4 ± 1.4	5.3 ± 1.9	6.4 ± 1.2	4.5 ± 2.3
	30	6.3 ± 1.4	7.5 ± 1.0	5.1 ± 2.0	5.8 ± 1.8	7.1 ± 0.8	5.1 ± 1.9
	36	7.5 ± 1.5	8.3 ± 1.3	6.3 ± 2.0	6.7 ± 2.1	7.8 ± 1.1	5.8 ± 2.2
Boys	6	3.1 ± 1.2	3.8 ± 1.0	2.6 ± 1.1	3.3 ± 1.6	3.8 ± 1.6	2.6 ± 2.3
	12	4.3 ± 1.3	4.9 ± 0.8	3.9 ± 1.6	4.4 ± 1.5	4.6 ± 1.6	3.4 ± 2.0
	18	4.9 ± 1.5	4.9 ± 1.2	4.1 ± 1.5	4.4 ± 1.5	4.8 ± 1.2	3.8 ± 1.3
	24	6.0 ± 1.7	6.3 ± 1.5	5.5 ± 1.7	5.8 ± 1.8	6.1 ± 1.6	5.0 ± 1.3
	30	5.5 ± 1.7	6.0 ± 1.3	4.8 ± 1.4	5.5 ± 1.8	5.9 ± 1.8	4.9 ± 1.4
	36	6.9 ± 1.7	7.8 ± 1.5	6.4 ± 1.6	6.4 ± 2.1	7.3 ± 2.1	5.6 ± 1.7

**Significant main effect for time for all RPE (body, leg, and chest) responses (6 min < 12 min = 18 min < 24 min = 30 min < 36 min)

during CHO. This suggests that administration of CHO during prolonged exercise of this nature might better ensure the maintenance of euglycemia in children. Others have observed that CHO administration serves to maintain higher blood glucose levels in children at the end of exercise than does the absence of CHO (Foricher et al. 2003; Timmons et al. 2003), although the nature of the CHO beverage may influence this response (Riddell et al. 2001). Interestingly, there was not a reduction in blood glucose level in boys during PL as has been demonstrated in some (Delamarche et al. 1992, 1994; Foricher et al. 2003), but not all steady-state exercise studies (Oseid and Hermansen 1971). How CHO use alters hormonal factors that regulate blood glucose levels in children is not entirely clear. Timmons et al. (2007a) reported that CHO use during 60 min of exercise at ~ 70% of VO_{2max} resulted in no difference in catecholamine concentration in 12- and 14-year-old girls compared to a water trial; however, CHO consumption blunted the increase in growth hormone observed in the water trial. Foricher et al. (2003) also found no effect of CHO on insulin and norepinephrine responses over 30 min of exercise at 60% of maximal work rate compared to a water trial, while epinephrine was significantly higher in CHO at 15 min, but not 30 min of exercise.

Pulmonary gas exchange measurements were assessed in the middle of the three bouts of VIE. The relative intensity during exercise ranged from ~ 68–73% peak VO_2 in both groups regardless of trial, although this belies the fact that, within the bouts of exercise, the percentage of physical work ranged from 25 to 125% of peak work rate. The similarity between groups with respect to %peak VO_2 indicates that the protocol was well matched for relative intensity. Relative to mass, there were no differences in VO_2 during VIE between groups. Although there are some limitations to using a ratio standard to compare groups, there is also debate on the best variable and method to allometrically scale for differences in body size (Loftin et al. 2016). There was a slight increase in the mean VO_2 during the VIE. This is likely due to a combination of the slow component of oxygen uptake kinetics (Gaesser and Poole 1996) and, perhaps, an accumulation of an oxygen debt from the supramaximal bouts. HR tended to be higher in boys regardless of the trial, although this difference was not statistically significant. CHO supplementation did not affect HR which is similar to observations in adolescent children performing the LIST protocol (Phillips et al. 2010, 2012). The increase in HR over time in the present study is consistent with the cardiovascular drift phenomenon and has been observed during prolonged steady-state exercise (Timmons and Bar-Or 2003; Timmons et al. 2003) and VIE (Phillips et al. 2012). There were expected differences in RER between group and trial as has been established in both children and adults by others (Ahlborg and Felig 1976; Riddell et al. 2000, 2001; Timmons et al. 2003, 2007b; Stephens et al. 2006). The lower RER in children versus adults during exercise has been attributed to lower muscle glycogen concentration and glycolytic activity in children (Eriksson et al. 1973; Eriksson and Saltin 1974; Aucouturier et al. 2008). The higher RER in both groups during the CHO trial indicates increased reliance on CHO as shown by the others (Ahlborg and Felig 1976; Riddell et al. 2000, 2001; Timmons et al. 2003, 2007a, b). However, because of the intensity of the protocol, it is likely that RER values in both trials were the result of both oxidative and non-oxidative CO_2 production. Finally, blood lactate increased with exercise in both boys and men, though the increase was larger in men. Higher blood lactate values in men compared to boys are well documented in the literature (Stephens et al. 2006; Timmons and Bar-Or 2003; Timmons et al. 2003). Ratel et al. (2004) found that ten 10-s sprints resulted in a ~ 6 mmol L^{-1} greater lactate accumulation in men compared to boys of a similar age to the boys in this study. There was no effect of trial on blood lactate concentration in the present study, which is consistent with some other studies (Foskett et al. 2008; Nicholas et al. 1995; Timmons et al. 2003), although other evidence indicates that CHO can either increase (Riddell et al. 2001; Timmons and Bar-Or 2003; Timmons et al. 2007b) or decrease (Riddell et al. 2000) blood lactate concentration during exercise. Factors accounting for the variation between studies are not entirely clear, but are likely due to differences in exercise protocol, subject populations, and CHO dose among studies.

All RPE measures increased over time in both groups, but there were no differences between groups for any of the RPE responses. In men, CHO use has been shown to decrease RPE_{body} and RPE_{leg}, but not RPE_{chest} during the later portion of prolonged, constant intensity exercise (Utter et al. 2007; Burgess et al. 1991). During prolonged (~ 60–90 min) intermittent exercise, RPE_{leg} also has been shown to be attenuated by CHO supplementation, but similarly not until late in exercise (Davis et al. 1997). In contrast, the other studies involving both children and adults have failed to observe any effect of CHO use on RPE responses during prolonged constant work exercise (Riddell et al. 2001; Timmons and Bar-Or 2003). In studies with adults performing exercise bouts more similar in intensity and duration to that in the present study, CHO supplementation does not appear to affect RPE (Snyder et al. 1993; de Sousa et al. 2007). CHO use also did not affect RPE during a varied-intensity shuttle running protocol (Ali et al. 2007; Foskett et al. 2008), although sprint (Foskett et al. 2008) and skill (Ali et al. 2007) performances were improved with CHO use. Similar results have been reported in the studies of adolescent boys (Phillips et al. 2010, 2012). Together, these findings suggest that, despite no perceptual benefit to CHO supplementation, subsequent performance may still be improved—a notion crucial to game play situations.

Some studies have observed lower RPE values in children compared to men during exercise at the same intensity (Bar-Or and Ward 1989) and during high-intensity, intermittent exercise (Ratel et al. 2004). In contrast, others have reported higher RPE in children than in adults during constant work exercise (Mahon et al. 2001; Timmons and Bar-Or 2003). In the present study, all RPE responses were similar between boys and men, regardless of trial. Reasons for the variations between studies are not clear, but differences in RPE scale, understanding the use of the scale and the ability to link perceptual ratings to a physiological response, and the nature of the exercise may all impact the outcomes. It is worth noting that, in the present study, although the three RPE (whole body, leg, and chest) ratings were not statistically compared to one another, the response pattern of $RPE_{leg} > RPE_{body} > RPE_{chest}$ between measures is comparable to the literature (Robertson et al. 2000).

There are limitations to the present study that should be noted. First and foremost, the sample size is small for both groups. Part of this is due to the loss of participants who originally volunteered for the study. Importantly, it should be noted that six subjects were not included, because they failed to meet the peak VO_2 criterion to participate. This criterion was included to increase the likelihood that both groups were evenly matched for cardiorespiratory fitness. One boy and one man were excluded because of withdrawal from the study and an error in correctly recording drink order, respectively. Nonetheless, four participants (two boys and two men) were unable to complete the VIE trials fully due to gastric discomfort and/or fatigue attesting to the intense nature of the exercise. Second, any benefit that CHO may have provided was mitigated by the exercise intensity. While the average relative intensity was similar between groups and was ~ 70% of peak VO_2, the variation in the actual physiological demand ranged from a mild intensity to a supramaximal intensity. Third, the pulmonary gas exchange and HR responses were obtained in non-steady-state conditions. Finally, no performance measurement was employed in this study; inclusion of a post-VIE performance test may have provided evidence of the beneficial effect of CHO supplementation.

CHO ingestion prior to and during VIE affected the blood glucose response to this type exercise differently in boys versus men and increased RER in both groups compared to a PL drink. Other physiological and perceptual responses to VIE were largely unaffected by the consumption of CHO. Further research examining the effect of growth and maturation and endocrine regulation of blood glucose with CHO ingestion as well as the potential performance enhancing impact consumption of CHO can have in children is recommended.

Author contributions LMG and ADM developed the study, participated in the data collection and analysis, and are the paper's primary authors. MPR and JPG assisted with some of the data collection and reviewed drafts of the paper prior to submission.

Funding This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Compliance with ethical standards

Conflict of interest None of the authors declare competing financial interests.

References

Ahlborg G, Felig P (1976) Influence of glucose ingestion on fuel-hormone response during prolonged exercise. J Appl Physiol 41(5 Pt. 1):683–688

Ali A, Williams C, Nicholas CW, Foskett A (2007) The influence of carbohydrate–electrolyte ingestion on soccer skill performance. Med Sci Sports Exerc 39(11):1969–1976. https://doi.org/10.1249/mss.0b013e31814fb3e3

Aucouturier J, Baker JS, Duche P (2008) Fat and carbohydrate metabolism during submaximal exercise in children. Sports Med 38(3):213–238

Bar-Or O, Ward DS (1989) Rating of perceived exertion in children. In: Bar-Or O (ed) Advances in pediatric sports sciences, vol 3. Human Kinetics Publishers, Champaign, pp 151–168

Burgess ML, Robertson RJ, Davis JM, Norris JM (1991) RPE, blood glucose, and carbohydrate oxidation during exercise: effects of glucose feedings. Med Sci Sports Exerc 23(3):353–359

Cheatham CC, Mahon AD, Brown JD, Bolster DR (2000) Cardiovascular responses during prolonged exercise at ventilatory threshold in boys and men. Med Sci Sports Exerc 32(6):1080–1087

Davis JM, Jackson DA, Broadwell MS, Queary JL, Lambert CL (1997) Carbohydrate drinks delay fatigue during intermittent, high-intensity cycling in active men and women. Int J Sport Nutr 7(4):261–273

de Sousa MV, Simoes HG, Oshiiwa M, Rogero MM, Tirapegui J (2007) Effects of acute carbohydrate supplementation during sessions of high-intensity intermittent exercise. Eur J Appl Physiol 99(1):57–63. https://doi.org/10.1007/s00421-006-0317-3

Delamarche P, Monnier M, Gratas-Delamarche A, Koubi HE, Mayet MH, Favier R (1992) Glucose and free fatty acid utilization during prolonged exercise in prepubertal boys in relation to catecholamine responses. Eur J Appl Physiol Occup Physiol 65(1):66–72

Delamarche P, Gratas-Delamarche A, Monnier M, Mayet MH, Koubi HE, Favier R (1994) Glucoregulation and hormonal changes during prolonged exercise in boys and girls. Eur J Appl Physiol Occup Physiol 68(1):3–8

Eriksson BO (1972) Physical training, oxygen supply and muscle metabolism in 11-13-year old boys. Acta Physiol Scand Suppl 384:1–48

Eriksson O, Saltin B (1974) Muscle metabolism during exercise in boys aged 11 to 16 years compared to adults. Acta Paediatr Belgica Suppl 28:257–265

Eriksson BO, Gollnick PD, Saltin B (1973) Muscle metabolism and enzyme activities after training in boys 11–13 years old. Acta Physiol Scand 87(4):485–497. https://doi.org/10.1111/j.1748-1716.1973.tb05415.x

Foricher JM, Boisseau N, Ville NS, Berthon PM, Bentue-Ferrer D, Gratas-Delamarche A, Delamarche P (2003) Effects of an oral

glucose challenge on metabolic and hormonal responses to exercise in active prepubertal girls. Pediatr Exerc Sci 15(3):266–276
Foskett A, Williams C, Boobis L, Tsintzas K (2008) Carbohydrate availability and muscle energy metabolism during intermittent running. Med Sci Sports Exerc 40:96–103. https://doi.org/10.1249/mss.0b013e3181586b2c
Gaesser GA, Poole DC (1996) The slow component of oxygen uptake kinetics in humans. Exerc Sport Sci Rev 24:35–71
Loftin M, Sothern M, Abe T, Bonis M (2016) Expression of VO_{2peak} in children and youth, with special reference to allometric scaling. Sports Med 46(10):1451–1460. https://doi.org/10.1007/s40279-016-0536-7
Maes BD, Ghoos YF, Geypens BJ, Hiele MI, Rutgeerts PJ (1995) Relation between gastric emptying rate and energy intake in children compared with adults. Gut 36(2):183–188
Mahon AD, Timmons BW (2014) Application of stable isotope tracers in the study of exercise metabolism in children: a primer. Pediatr Exerc Sci 26(1):3–10. https://doi.org/10.1123/pes.2013-0074
Mahon AD, Stolen KQ, Gay JA (2001) Differentiated perceived exertion during submaximal exercise in children and adults. Pediatr Exerc Sci 13:145–153
Mahon AD, Guth LM, Kraft KA (2010) Physiological and perceptual responses in children during variable-intensity exercise. In: Baquet G, Berthoin S (eds) Children and exercise XXV. Routledge, London, pp 171–177
Martinez LR, Haymes EM (1992) Substrate utilization during treadmill running in prepubertal girls and women. Med Sci Sports Exerc 24(9):975–983
Nicholas CW, Williams C, Lakomy HK, Phillips G, Nowitz A (1995) Influence of ingesting a carbohydrate-electrolyte solution on endurance capacity during intermittent, high-intensity shuttle running. J Sports Sci 13(4):283–290
Noble BJ, Robertson RJ (1996) Perceived exertion. Human Kinetics, Champaign
Oseid S, Hermansen L (1971) Hormonal and metabolic changes during and after prolonged muscular work in pre-pubertal boys. Acta Paediatr Scand Suppl 217:147–153
Passonneau JV, Lowry OH (1993) Enzymatic analysis: a practical guide. Biological methods. Humana Press, Totowa
Phillips SM, Turner AP, Gray S, Sanderson MF, Sproule J (2010) 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. Eur J Appl Physiol 109(5):811–821. https://doi.org/10.1007/s00421-010-1404-z
Phillips SM, Turner AP, Sanderson MF, Sproule J (2012) Carbohydrate gel ingestion significantly improves the intermittent endurance capacity, but not sprint performance, of adolescent team games players during a simulated team games protocol. Eur J Appl Physiol 112(3):1133–1141. https://doi.org/10.1007/s00421-011-2067-0
Ratel S, Williams CA, Oliver J, Armstrong N (2004) Effects of age and mode of exercise on power output profiles during repeated sprints. Eur J Appl Physiol 92(1–2):204–210. https://doi.org/10.1007/s00421-004-1081-x
Riddell MC (2008) The endocrine response and substrate utilization during exercise in children and adolescents. J Appl Physiol 105(2):725–733. https://doi.org/10.1152/japplphysiol.00031.2008
Riddell MC, Bar-Or O, Schwarcz HP, Heigenhauser GJ (2000) Substrate utilization in boys during exercise with [13C]-glucose ingestion. Eur J Appl Physiol 83(4–5):441–448
Riddell MC, Bar-Or O, Wilk B, Parolin ML, Heigenhauser GJ (2001) Substrate utilization during exercise with glucose and glucose plus fructose ingestion in boys ages 10–14 year. J Appl Physiol 90(3):903–911
Robertson RJ, Goss FL, Boer NF, Peoples JA, Foreman AJ, Dabayebeh IM, Millich NB, Balasekaran G, Riechman SE, Gallagher JD, Thompkins T (2000) Children's OMNI scale of perceived exertion: mixed gender and race validation. Med Sci Sports Exerc 32(2):452–458
Snyder AC, Moorhead K, Luedtke J, Small M (1993) Carbohydrate consumption prior to repeated bouts of high-intensity exercise. Eur J Appl Physiol Occup Physiol 66(2):141–145
Stephens BR, Cole AS, Mahon AD (2006) The influence of biological maturation on fat and carbohydrate metabolism during exercise in males. Int J Sport Nutr Exerc Metab 16(2):166–179
Stevens J (2002) Applied multivariate statistics for the social sciences. Lawrence Erlbaum Associates, Mahwah
Tanner JM (1962) Growth at adolescence, with a general consideration of the effects of hereditary and environmental factors upon growth and maturation from birth to maturity, 2d edn. Blackwell Scientific Publications, Oxford
Timmons BW, Bar-Or O (2003) RPE during prolonged cycling with and without carbohydrate ingestion in boys and men. Med Sci Sports Exerc 35(11):1901–1907
Timmons BW, Bar-Or O, Riddell MC (2003) Oxidation rate of exogenous carbohydrate during exercise is higher in boys than in men. J Appl Physiol 94(1):278–284
Timmons BW, Bar-Or O, Riddell MC (2007a) Energy substrate utilization during prolonged exercise with and without carbohydrate intake in preadolescent and adolescent girls. J Appl Physiol 103(3):995–1000
Timmons BW, Bar-Or O, Riddell MC (2007b) Influence of age and pubertal status on substrate utilization during exercise with and without carbohydrate intake in healthy boys. Appl Physiol Nutr Metab 32(3):416–425
Utter AC, Kang J, Nieman DC, Dumke CL, McAnulty SR, McAnulty LS (2007) Carbohydrate attenuates perceived exertion during intermittent exercise and recovery. Med Sci Sports Exerc 39(5):880–885. https://doi.org/10.1249/mss.0b013e31803174a8