Oxidation rate of exogenous carbohydrate during exercise is higher in boys than in men

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Oxidation rate of exogenous carbohydrate during exercise is higher in boys than in men. J Appl Physiol 94: 278–284, 2003. First published September 13, 2002; 10.1152/japplphysiol.00140.2002.—To determine whether the relative utilization of exogenous carbohydrate (CHOexo) differs between children and adults, substrate utilization during 60 min of cycling at 70% peak O2 uptake was studied in 12 pre- and early pubertal boys (9.8 ± 0.1 yr) and 10 men (22.1 ± 0.5 yr) on two occasions. Subjects consumed either a placebo or a 13C-enriched 6% CHOexo beverage (total volume per trial: 24 ml/kg). Substrate utilization was calculated for the final 30 min of exercise. During both trials, total fat oxidation was higher (5.4 ± 0.5 vs. 3.0 ± 0.4 mg·kg⁻¹·min⁻¹, P < 0.001) and total CHO oxidation lower (27.4 ± 1.5 vs. 34.8 ± 1.2 mg·kg⁻¹·min⁻¹, P < 0.001) in boys than in men, respectively. During the CHOexo trial, CHOexo oxidation was higher (P < 0.001) in boys (8.8 ± 0.5 mg·kg⁻¹·min⁻¹) than in men (6.2 ± 0.5 mg·kg⁻¹·min⁻¹) and provided a greater (P < 0.001) relative proportion of total energy in boys (21.8 ± 1.4%) than in men (14.6 ± 0.9%). These results suggest that, although endogenous CHO utilization during exercise is lower, the relative oxidation of ingested CHO is considerably higher in boys than in men. The greater reliance on CHOexo in boys may be important in preserving endogenous fuels and may be related to pubertal status.

DURING ENDURANCE EXERCISE, carbohydrate (CHO) and fat are the primary nutrients utilized as fuel. Their relative use depends largely on the intensity and duration of exercise (35). However, the metabolic response to exercise can also be manipulated in adults (3, 11) and in children (31–33) by ingesting CHO before and during the activity. In adult men, exogenous CHO (CHOexo) fed during prolonged exercise increases, or at least maintains, plasma glucose levels (1, 12) and high rates of plasma glucose oxidation late in exercise (8), thereby resulting in improved endurance. These effects of CHOexo have also been documented in adolescent boys (31–33). In adults, the apparent maximal rate of CHOexo oxidation during prolonged exercise is ~1 g/min (17), and the contribution of CHOexo oxidation to total energy expenditure ranges from 10 to 20% during exercise lasting 60–120 min (10, 21, 29). Several factors seem to affect the rate of CHOexo oxidation, including the rate of CHOexo ingestion (25, 30) and exercise intensity (22, 29). However, maturity status has not been investigated as a possible factor influencing the rate of CHOexo oxidation during exercise.

Considerable evidence suggests that children have a lower respiratory exchange ratio (RER) than adolescents and adults during submaximal exercise performed at the same absolute (34, 36) and relative (19, 20) intensity. The lower RER in children indicates that they utilize more fat and less CHO for energy at a given intensity of exercise. The relative utilization of CHOexo during exercise, however, has not been directly compared between children and adults, and it is also unclear how CHOexo may affect endogenous substrate utilization during exercise in children compared with adults. Recent work from our laboratory suggests that the contribution of CHOexo to total energy metabolism is higher in children and adolescents compared with what has been reported for adults (31–33). However, these studies were not designed to directly compare children with adults, and definitive proof of age- or maturity-related differences in CHOexo oxidation and energy metabolism is, therefore, lacking.

Considering our present understanding of CHOexo oxidation in adults and of substrate utilization in children, we wished to directly compare the effects of CHOexo on energy metabolism between children and adults during exercise performed at the same relative intensity. On the basis of our earlier observations, we hypothesized that, compared with adults, young children would oxidize relatively more CHOexo during exercise and that CHOexo would contribute proportionately more to total energy metabolism. To test this hypothesis, we compared the rate of CHOexo oxidation (by 13C stable isotope methodology) in a group of pre- and early pubertal boys with a group of adult men exercising at a similar intensity and ingesting CHOexo at identical rates, relative to their body weight (BW).
EXOGENOUS CHO OXIDATION IN BOYS AND MEN

METHODS

Subjects. Twelve boys and ten men volunteered to participate in this study, which was approved by the McMaster University Research Ethics Review Board. Their physical and fitness characteristics are summarized in Table 1. Pubertal status of the boys was determined according to pubic hair development by the criteria of Tanner (39) assessed by a parent and the child. Boys were either Tanner stage 1 \( (n = 8) \) or Tanner stage 2 \( (n = 4) \). All subjects were healthy, non-obese, not taking any medication, and were recreationally active but not competitive athletes. After the purpose, procedures, and risks of the study were explained to each subject, the men signed an informed consent, and the boys assented verbally to participate. Each boy’s parent then signed an informed consent on his or her son’s behalf.

Initial testing. Each subject visited the Children’s Exercise and Nutrition Centre for an initial session to collect anthropometric data, including height (Harpenden Stadiometer, CMS Weighing Equipment), naked BW (BWB-800, Tanita), and percent body fat (Bioimpedance-Analyzer-101A, RJL CMS Weighing Equipment), and percent body fat (Bioimpedance-Analyzer-101A, RJL CMS Weighing Equipment), and percent body fat (Bioimpedance-Analyzer-101A, RJL CMS Weighing Equipment). Heart rate (HR) was recorded continuously throughout the test by using a Polar HR monitor (Polar Vantage XL, Polar Electro). The initial testing was completed at least 1 wk before the experimental trials.

Experimental trials. On two occasions, separated by 1–2 wk, subjects cycled at 70% of their individual \( \dot{V}O_2 \) peak for two 30-min periods separated by a 5-min rest period. Trials were identical except for CHO intake before and during exercise. In the CHO trial (CT), each subject consumed a 6% CHO-electrolyte solution (4% sucrose, 2% glucose, \(-18 \) mmol/l \( \text{Na}^+\), \(-3 \) mmol/l \( \text{K}^+\)) and, in the placebo trial (PT), an artificially sweetened beverage (identical in flavor and electrolyte concentration but without CHO) before and intermittently throughout exercise. The total volume of beverage consumed was 24 ml/kg BW per trial. Both beverages were prepared in powder form by the Gatorade Sports Science Institute (Barrington, IL). The CHO drink was artificially enriched with uniformly labeled \( ^{13}\text{C} \) sucrose and \( ^{13}\text{C} \) glucose (in a 2:1 ratio) to an isotopic composition of \( +20.883\%\) change per 1,000 \( ^{13}\text{C} \) Pee Dee Belemnite-1 (PDB-1) \( (+20.883\%\) [5-\( ^{13}\text{C} \) PDB-1]). The sequence of the experimental trials was counterbalanced, and only the subjects were blinded to the contents of their drink.

Experimental protocol. On the day before each trial, activity level and nutrient intake were standardized for each subject according to their habitual routines. This was achieved by having physical activity and dietary intake recorded the day before their first trial and then repeated the day before the next visit. In addition, subjects avoided corn products, or food derived from corn, to reduce background enrichment of expired \( \text{CO}_2 \) from naturally derived \( ^{13}\text{C} \) (37). Subjects arrived at the laboratory in the morning \( (~0730) \) after an overnight fast and were given a small standardized breakfast (boys: 125 ml tap water and 1 slice of toast with sugar-free jam \(-90\) kcal; men: twice that amount). After eating, subjects emptied their bladder, and a naked weight was taken (BWB-800) to calculate the volume of fluid intake for that session. After the subjects sat quietly for \(-20\) min, a resting expired gas sample was collected for 3 min, and a preexercise blood sample was drawn from an arm vein through a “butterfly” winged infusion set (Terumo). Subjects were then given their first drink (4 ml/kg BW) 30 min before the start of exercise \( (t = -30 \) min) and consumed the same volume at five subsequent time points \( (t = -15, 0, 15, 30, \) and 50 min) of exercise. Exercise began 30 min after the resting blood sample, and the target exercise intensity was verified within the first 5 min. The pedaling rate remained constant at 60 rpm throughout exercise. Subsequent expired gas samples were collected for a 3-min period starting at the 12th and 27th min of each exercise bout. Immediately after exercise, a second blood sample was drawn while subjects remained seated on the cycle ergometer. HR was monitored throughout exercise.

Substrate utilization. For each period of gas collection, oxidation rates of total CHO (CHO$_{\text{total}}$) and total fat (Fat$_{\text{total}}$) were calculated according to the following equations (28)

\[
\text{CHO}_{\text{total}} \text{(g/min)} = 4.59 - \dot{V}O_2 \text{ (l/min)} - 3.23 \cdot \dot{V}CO_2 \text{ (l/min)}
\]

\[
\text{Fat}_{\text{total}} \text{(g/min)} = -1.70 \cdot \dot{V}O_2 \text{ (l/min)} + 1.69 \cdot \dot{V}CO_2 \text{ (l/min)}
\]

The energy provided from CHO and fat oxidation was calculated from their energy potentials \((3.87 \text{ and } 9.75 \text{ kcal/g, respectively})\). To measure the ratio of \( ^{13}\text{C}/^{12}\text{C} \) in the expired \( \text{CO}_2 \), a 20-ml syringe was used to draw a sample of the expired gas directly from the tube connecting the subject’s mouthpiece to the metabolic cart. Sampling did not interfere with the subject exercising. Duplicate samples (10 ml) were emptied from the syringe into vacutainer tubes (Becton Dickinson) and subsequently analyzed for the ratio of \( ^{13}\text{C}/^{12}\text{C} \) in the expired \( \text{CO}_2 \) (BreathMat Plus, Finnigan MAT). CHO$_{\text{exo}}$ oxidation was then calculated for the sampling periods according to the following equation modified from Mosora et al. (24)

\[
\text{CHO}_{\text{exo}} \text{(g/min)} = \dot{V}CO_2 \cdot \frac{(R_{\text{exp}} - R_{\text{ref}})/(R_{\text{ref}} - R_{\text{cell}})}{\text{V}O_2/(\text{V}O_2 - \text{R}_{\text{ref}})} \text{ (l/kg)}
\]

where \( \text{V}O_2 \text{ (l/min)} \) is in STPD, \( R_{\text{ref}} \) is the isotopic composition of expired \( \text{CO}_2 \) during CT, \( R_{\text{exo}} \) is the isotopic composition of expired \( \text{CO}_2 \) during PT at the corresponding time point, \( R_{\text{cell}} \) is the isotopic composition of the CHO$_{\text{exo}}$, and \( k \) \((0.7426 \text{ l/g})\) is the volume of \( \text{CO}_2 \) produced by the complete oxidation of 1 g of glucose. Endogenous CHO (CHO$_{\text{endo}}$) oxidation was calculated by subtracting CHO$_{\text{exo}}$ from CHO$_{\text{total}}$. Because of the presence of a large bicarbonate pool in the body and because of the delay in measuring \( ^{13}\text{CO}_2 \) production by the tissues at the mouth (26), computations of CHO$_{\text{exo}}$ oxidation were made for the last 30 min of exercise only.

Plasma glucose and lactate. Whole blood \((~2 \text{ ml})\) was added to an EDTA-containing vacutainer (Becton Dickinson) and centrifuged \((2,000 \text{ g} \text{ for } 10 \text{ min at } 5\text{C})\). The supernatant was removed and stored at \(-70\text{C} \) for subsequent analysis of plasma glucose and lactate (YSI 2300L STAT, Yellow Springs Instrument Co., Yellow Springs, OH).

Table 1. Subjects’ physical and fitness characteristics

<table>
<thead>
<tr>
<th></th>
<th>Boys</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Age, yr</td>
<td>9.8 ± 0.1</td>
<td>22.1 ± 0.5( ^a )</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.42 ± 0.03</td>
<td>1.77 ± 0.02( ^a )</td>
</tr>
<tr>
<td>Body weight, kg</td>
<td>35.1 ± 1.8</td>
<td>82.6 ± 5.0( ^a )</td>
</tr>
<tr>
<td>Body fat, %</td>
<td>15.9 ± 1.7</td>
<td>16.9 ± 1.1</td>
</tr>
<tr>
<td>( \dot{V}O_{2\text{peak}}, \text{ml}\text{-kg}^{-1}\cdot\text{min}^{-1} )</td>
<td>45.2 ± 1.2</td>
<td>43.8 ± 1.6</td>
</tr>
<tr>
<td>( \dot{H}R_{\text{max}}, \text{beats/min} )</td>
<td>197 ± 2</td>
<td>194 ± 3</td>
</tr>
</tbody>
</table>

Values are means ± SE; \( n \), no. of subjects; \( \dot{V}O_{2\text{peak}} \), peak \( \dot{O}_2 \) uptake; \( \dot{H}R_{\text{max}} \), maximal heart rate. \( ^a \)Significant difference between boys and men, \( P < 0.05 \).
Instruments). Values were corrected for changes in plasma volume according to Dill and Costill (13).

**Statistical analyses.** Data are presented as means ± SE and were analyzed by using a statistical software package (STATISTICA for Windows 5.0, StatSoft). Differences in physical and fitness characteristics were compared with independent t-tests. The averaged substrate oxidation responses of the two groups were compared with a two-way (group × trial) ANOVA. Significance in all other variables was determined by using a three-way ANOVA with one between factor (group) and two within factors (trial and time). Where appropriate, Tukey’s honestly significant difference post hoc test for unequal sample size was used to determine the location of significance among means. The threshold for statistical significance was set at $P < 0.05$ for all tests.

**RESULTS**

**HR and $\dot{V}_O_2$.** As expected, the average resting HR in both trials was higher ($P < 0.001$) in the boys (73 ± 3 beats/min) than in the men (57 ± 2 beats/min). During exercise, there were no differences between groups for average HR or the percentage of maximal HR (HR\(_{\text{max}}\)) achieved in either trial. However, the average HR for both groups during PT (156 ± 2 beats/min) was slightly lower ($P = 0.02$) than during CT (160 ± 2 beats/min). Figure 1 displays the percentage of HR\(_{\text{max}}\) achieved during exercise in PT and CT for both groups. The percentage of HR\(_{\text{max}}\) achieved increased over time (main effect, $P < 0.001$), and this increase was slower in the boys compared with the men (group × time interaction, $P < 0.001$) during the first 30 min of exercise only. Table 2 summarizes the $\dot{V}_O_2$ during exercise for the boys and the men in both trials. $\dot{V}_O_2$ expressed relative to BW did not differ between the groups, but the percentage of $\dot{V}_O_2$\(_{\text{peak}}\) averaged across trials was slightly lower ($P = 0.01$) in the boys than in the men. However, when exercise intensity was expressed as a percentage of each subject’s ventilatory threshold, there was no difference between boys and men (data not shown).

**RER and breath enrichment.** The average resting RER for both trials was not different between the boys (0.84 ± 0.01) and the men (0.84 ± 0.03). The average RER during exercise in PT was significantly lower ($P < 0.001$) in the boys than in the men and decreased over time ($P < 0.001$) from 0.91 ± 0.01 to 0.88 ± 0.01 in the boys and from 0.96 ± 0.01 to 0.93 ± 0.01 in the men (Fig. 2). In CT, the average RER during exercise was also significantly lower ($P < 0.001$) in the boys than in the men and decreased from 0.96 ± 0.01 to 0.94 ± 0.01 ($P < 0.05$) in the men but remained relatively constant at 0.91 ± 0.01 in the boys.

There were no differences in the isotopic composition of expired CO\(_2\) at rest between groups or between trials (pooled average = $-22.1 ± 0.4\%$ [δ\(^{13}\)C/PDB-1]). Figure 3 shows the changes in breath enrichment during exercise in PT and CT. During PT, the ratio of $^{13}\text{C}/^{12}\text{C}$ in expired CO\(_2\) increased slightly but significantly ($P < 0.05$) with exercise in the men but remained relatively unchanged in the boys. During CT, the $^{13}\text{C}/^{12}\text{C}$ in expired CO\(_2\) increased markedly with exercise in both groups, indicating a strong measurement signal.

### Table 2. $\dot{V}_O_2$ during exercise in placebo and carbohydrate trials for boys and men

<table>
<thead>
<tr>
<th></th>
<th>$\dot{V}_O_2$, l/min⁻¹</th>
<th>$\dot{V}_O_2$, ml·kg⁻¹·min⁻¹</th>
<th>$\dot{V}<em>O_2$(</em>{\text{peak}}), %</th>
<th>$\dot{V}_E$, l/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boys</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td>1.1 ± 0.1</td>
<td>31.4 ± 1.3</td>
<td>69.5 ± 1.6</td>
<td>30.8 ± 1.4</td>
</tr>
<tr>
<td>PT</td>
<td>1.1 ± 0.0</td>
<td>31.2 ± 1.1</td>
<td>69.0 ± 1.3</td>
<td>30.2 ± 1.2</td>
</tr>
<tr>
<td>Men</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td>2.6 ± 0.1</td>
<td>31.9 ± 1.0</td>
<td>73.0 ± 0.8</td>
<td>65.4 ± 2.3</td>
</tr>
<tr>
<td>PT</td>
<td>2.6 ± 0.1</td>
<td>32.1 ± 1.0</td>
<td>73.6 ± 1.2</td>
<td>65.4 ± 2.2</td>
</tr>
</tbody>
</table>

Values are means ± SE. CT, carbohydrate trial; PT, placebo trial. $\dot{V}_O_2$, $\dot{O}_2$ uptake; $\dot{V}_E$, minute ventilation. There was a main effect of group for $\dot{V}_O_2$, $\dot{V}_O_2$\(_{\text{peak}}\), and $\dot{V}_E$, $P < 0.05$. 

![Fig. 1. Percentage of maximal heart rate (HR) achieved during exercise in placebo (PT; open symbols) and carbohydrate trials (CT; solid symbols) for boys (circles) and men (squares). Values are means ± SE. Hatched bars represent exercise. *Significant difference between PT and CT, $P < 0.05$. †Main effect for group, $P < 0.05$. ‡Sixty-five-minute value for boys and men in PT and men in CT significantly different from 15-min value in same trial, $P < 0.05$.](#)
compared with rest, but was significantly higher ($P < 0.001$) in the boys at all time points.

Substrate utilization. Oxidation rates and percent energy contributions for CHO$_{total}$, CHO$_{endo}$, CHO$_{exo}$, and Fat$_{total}$ are reported for the final 30 min of exercise only. To control for the effect of body size on absolute values of substrate utilization, oxidation rates were expressed relative to BW (i.e., mg·kg$^{-1}$·min$^{-1}$, Table 3). In both trials, average CHO$_{total}$ oxidation was significantly lower ($P < 0.001$), and average Fat$_{total}$ oxidation was significantly higher ($P < 0.001$), in the boys compared with the men. Main effects for trial approached significance, with CHO$_{total}$ oxidation.tending to be lower ($P = 0.07$) and Fat$_{total}$ oxidation to be higher ($P = 0.08$) in PT compared with CT. During CT, CHO$_{endo}$ oxidation was lower ($P < 0.001$) and CHO$_{exo}$ oxidation higher ($P < 0.01$) in the boys compared with the men. Compared with PT, CHO$_{endo}$ oxidation during the last 30 min of exercise in CT was reduced by $24.2 \pm 6.3\%$ in the boys and by $14.7 \pm 3.0\%$ in the men. However, because of within-group variability, this difference did not reach statistical significance ($P = 0.2$). We, therefore, examined the individual data and found a similar pattern whereby 10 out of 12 boys and 9 out of 10 men had a reduced CHO$_{endo}$ oxidation in CT compared with PT. The percent reduction for this subgroup of subjects who spared CHO$_{endo}$ was $32.5 \pm 3.2\%$ in the boys and $16.5 \pm 2.5\%$ in the men ($P < 0.01$). Similar to the CHO$_{endo}$ oxidation data, within-group variability for Fat$_{total}$ oxidation during CT precluded a statistically significant ($P = 0.5$) difference in Fat$_{total}$ sparing between boys $(10.5 \pm 8.4\%)$ and men $(4.8 \pm 23.0\%)$. Examination of the individual data revealed that Fat$_{total}$ oxidation was unchanged in 1 boy and 2 men but was reduced in 7 out of 12 boys and 5 out of 10 men in CT compared with PT. There was no difference between the boys and men who reduced Fat$_{total}$ oxidation during PT (pooled average $= 33.7 \pm 6.3\%$). CHO$_{exo}$ oxidation increased over time ($P < 0.001$) during CT in both groups but was significantly higher ($P < 0.01$) in the boys at all time points (Table 3). The total amount of CHO$_{exo}$ oxidized over the last 30 min of exercise was $9.2 \pm 0.6$ and $15.5 \pm 1.2$ g in the boys and men, respectively ($P < 0.001$). To determine the oxidation efficiency of the ingested CHO$_{exo}$, the rate of CHO$_{exo}$ oxidation was divided by the CHO$_{exo}$ ingestion rate and expressed as a percentage. The oxidation efficiency was $36.8 \pm 2.0\%$ in the boys vs. $26.0 \pm 2.1\%$ in the men ($P < 0.01$).

To account for intergroup differences in energy expenditure, the percentage of total energy provided from CHO$_{endo}$, CHO$_{exo}$, and Fat$_{total}$ oxidation was calculated. The relative contributions of CHO$_{endo}$, CHO$_{exo}$, and Fat$_{total}$ oxidation over the last 30 min of exercise in both trials are shown in Fig. 4. During PT, the contribution of Fat$_{total}$ oxidation to total energy increased significantly ($P < 0.001$) from $23.2 \pm 2.3\%$ at 30 min to $37.9 \pm 2.6\%$ at 60 min of exercise in the boys and from $15.0 \pm 1.8$ to $21.6 \pm 2.4\%$, respectively, in the men. The average energy contribution from Fat$_{total}$ was significantly higher ($P < 0.001$) in the boys ($35.5 \pm 2.3\%$) than in the men ($19.0 \pm 1.8\%$). During CT, the percent contribution from Fat$_{total}$ did not change over time in the boys and increased slightly ($13.6 \pm 2.2$ to $18.9 \pm 2.5\%$).

![Fig. 3. Ratio of $^{13}$C/$^{12}$C in expired air [‰ vs. Pee Dee Bellemnita](PDB) at rest and during exercise in PT (open symbols) and CT trials (solid symbols) for boys (circles) and men (squares). Values are means ± SE. Hatched bars represent exercise. *Significant difference between boys and men within trial, $P < 0.05$. †Significant main effect for trial, $P < 0.05$. ‡Significant time interaction (CHO$_{endo}$), $P < 0.05$. ‡Significantly different than 30 min within trial, $P < 0.05$. Main effect for time (CHO$_{endo}$, CHO$_{exo}$, CHO$_{total}$, Fat$_{total}$), $P < 0.05$. *Significantly different than 30 min within trial, $P < 0.05$. Main effect for trial (CHO$_{endo}$), $P < 0.05$. Trial × time interaction (CHO$_{endo}$), $P < 0.05$. ‡Significantly different than PT at same time point, $P < 0.05$.](http://jap.physiology.org/)

**Table 3. Substrate utilization during last 30 min of exercise in PT and CT for boys and men**

<table>
<thead>
<tr>
<th></th>
<th>CHO$_{total}$</th>
<th>CHO$_{exo}$</th>
<th>CHO$_{endo}$</th>
<th>Fat$_{total}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CT</td>
<td>PT</td>
<td>CT</td>
<td>PT</td>
</tr>
<tr>
<td>Boys</td>
<td></td>
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</tr>
<tr>
<td>30 min</td>
<td>29.1 ± 1.6*</td>
<td>27.6 ± 1.2*</td>
<td>6.4 ± 0.5*</td>
<td>22.8 ± 1.8†</td>
</tr>
<tr>
<td>45 min</td>
<td>28.2 ± 1.7*</td>
<td>25.7 ± 1.2*</td>
<td>9.4 ± 0.7†</td>
<td>18.9 ± 1.8†</td>
</tr>
<tr>
<td>60 min</td>
<td>28.6 ± 2.0†</td>
<td>25.3 ± 1.4*</td>
<td>10.7 ± 0.4†</td>
<td>17.9 ± 2.0†</td>
</tr>
<tr>
<td>Men</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 min</td>
<td>37.1 ± 1.5</td>
<td>36.4 ± 1.0</td>
<td>3.9 ± 0.3</td>
<td>33.2 ± 1.4†</td>
</tr>
<tr>
<td>45 min</td>
<td>34.4 ± 1.2</td>
<td>33.2 ± 1.2†</td>
<td>6.4 ± 0.5†</td>
<td>27.9 ± 1.0†</td>
</tr>
<tr>
<td>60 min</td>
<td>34.6 ± 1.5</td>
<td>33.0 ± 0.9†</td>
<td>8.4 ± 0.7†</td>
<td>28.2 ± 1.2†</td>
</tr>
</tbody>
</table>

Values are means ± SE given in mg·kg$^{-1}$·min$^{-1}$. CHO$_{total}$, total carbohydrate oxidation; CHO$_{exo}$, exogenous carbohydrate oxidation; CHO$_{endo}$, endogenous carbohydrate oxidation; Fat$_{total}$, total fat oxidation. Main effect for group (CHO$_{total}$, CHO$_{exo}$, CHO$_{endo}$, Fat$_{total}$), $P < 0.05$. *Significantly different than 30 min within trial, $P < 0.05$. Main effect for time (CHO$_{total}$, CHO$_{exo}$, CHO$_{endo}$, Fat$_{total}$), $P < 0.05$. †Significantly different than 30 min within trial, $P < 0.05$. Main effect for trial (CHO$_{endo}$), $P < 0.05$. Trial × time interaction (CHO$_{endo}$), $P < 0.05$. ‡Significantly different than PT at same time point, $P < 0.05$. 

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1.7%) in the men (P = 0.08). However, the average percent contribution remained significantly higher (P < 0.001) in the boys (30.5 ± 2.6%) than in the men (16.7 ± 1.8%). During PT, the percent energy contribution of CHOtotal decreased over time (P < 0.05) from 67.7 ± 2.3 to 62.1 ± 2.6% in the boys and from 85.0 ± 1.8 to 78.4 ± 2.4% in the men. The average percentage of energy provided was 64.5 ± 2.2% in the boys and 81.1 ± 1.8% in the men (P < 0.001). During CT, the contribution of CHOtotal remained stable in the boys at 69.5 ± 2.7% but decreased slightly in the men (86.4 ± 2.2 to 81.1 ± 1.7%, P = 0.08). The percentage of energy derived from CHOendo during CT decreased over time (P < 0.001) from 54.1 ± 3.1 to 42.6 ± 3.3% in the boys and from 77.5 ± 2.5 to 61.5 ± 2.2% in the men. CHOendo provided, on average, 47.7 ± 3.1% of the total energy in the boys and 52.8 ± 2.2% in the men (P < 0.001). The contribution of CHOexo oxidation to total energy metabolism increased over time (P < 0.001) in the boys (15.7 ± 1.3 to 26.5 ± 1.4%) and in the men (9.0 ± 0.6 to 19.6 ± 1.4%), but the average contribution was significantly higher (P < 0.001) in the boys (21.8 ± 1.4%) than in the men (14.6 ± 0.9%).

**Glucose and lactate.** Plasma glucose ([glucose]) and lactate concentration ([lactate]) are shown in Table 4. Preexercise [glucose], averaged across trials, was slightly lower in the boys (5.99 ± 0.18 mmol/l) than in the men (6.67 ± 0.39 mmol/l), but this difference did not reach statistical significance (P = 0.10). Regardless of group, the postexercise [glucose] was lower (P < 0.001) in PT than in CT but was not different between groups in either trial.

There were no differences in preexercise [lactate] between groups or trials. The increase in [lactate] postexercise in CT was different from PT for men, but it tended to be higher (P = 0.06) in CT than in PT for the boys. Postexercise [lactate], averaged across trials, was lower (P < 0.001) in the boys (1.78 ± 0.16 mmol/l) than in the men (3.81 ± 0.51 mmol/l).

**DISCUSSION**

Previous investigations have shown that children utilize proportionally more fat and less CHO compared with adults during exercise performed at the same relative intensity (19, 20). Our data support these findings in that, compared with the men, the boys utilized ~70% more fat and ~23% less CHO during exercise performed without CHOexo (Table 3). We also extend previous findings by showing that this pattern of fuel preference is maintained when exercise is performed with CHOexo feeding (Table 3, Fig. 4). The main finding, however, is that the oxidation rate of CHOexo, relative to BW, is considerably higher (~37%) in young boys compared with adult men during exercise performed at ~70% VO₂peak (Table 3). Consequently, the relative contribution of CHOexo oxidation to total energy metabolism is also considerably higher in boys (~22%) compared with men (~15%, Fig. 4).

Two hypotheses may help explain the preferential use of fat as fuel during submaximal exercise in young children compared with adults. First, children may have a relatively higher endogenous fat oxidation due to a higher intramuscular triglyceride (IMTG) availability compared with adults (7). This is supported by a recent study (38) of adult women in whom a higher resting concentration of IMTG resulted in a greater

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**Table 4. Glucose and lactate responses to exercise in placebo and carbohydrate trials for boys and men**

<table>
<thead>
<tr>
<th></th>
<th>Glucose</th>
<th>Lactate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Boys</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td>6.0 ± 0.2</td>
<td>5.7 ± 0.2†</td>
</tr>
<tr>
<td>PT</td>
<td>6.0 ± 0.2*</td>
<td>4.9 ± 0.1†</td>
</tr>
<tr>
<td>Men</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td>6.6 ± 0.4</td>
<td>5.5 ± 0.1†</td>
</tr>
<tr>
<td>PT</td>
<td>6.7 ± 0.4</td>
<td>4.5 ± 0.1†</td>
</tr>
</tbody>
</table>

Values are means ± SE in mmol/l. Pre, before exercise; Post, after exercise. *Significantly different than men, P < 0.05. †Significantly different than Pre, P < 0.05. ‡Significantly different than PT, P < 0.05.

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utilization of this endogenous fuel during subsequent submaximal exercise. Alternatively, the higher fat oxidation in boys may have been a default mechanism due to an underdeveloped glycogenolytic and/or glycolytic system. However, because of ethical limitations in measuring muscle enzyme activity and endogenous substrate concentrations, innovative approaches will be required to resolve the above issues in the pediatric population.

That children rely more on fat than CHO during exercise, compared with adults, parallels the observation that adult women also utilize proportionally more fat during exercise than do adult men (16, 40). Although the mechanisms responsible for gender differences in substrate metabolism in adults are debatable (9), higher concentrations of IMTG have been implicated (38). Interestingly, higher rates of CHOexo oxidation have also been reported for women compared with men, despite their higher relative utilization of fat (23, 27). Therefore, future studies should include both boys and girls to determine possible gender differences in substrate metabolism among children.

This study is the first to show that Fattotal oxidation remains considerably higher (~88%) in boys than in men, even during CHOexo feeding (Table 3). This higher rate of fat oxidation, despite an increase in plasma glucose availability, has previously been shown in trained vs. sedentary adults (10, 18). However, the most novel finding of our study is that the rate of CHOexo oxidation, relative to BW, is significantly higher (~37%) in young boys compared with adult men (Table 3). The relative CHOexo oxidation rate of our men (~0.19 g/kg) is comparable to previous findings for untrained adults, ~0.20 g/kg (29) and ~0.23 g/kg (10), exercising at similar intensities as in the present study. The rate of CHOexo oxidation in our boys (~0.26 g/kg) is similar to values previously reported for trained (10) adults but is higher than for untrained (10, 29) adults. This value is also higher than our laboratory’s previous findings of ~0.17 g/kg for boys aged 11–14 yr (33) and ~0.20 g/kg for boys aged 14–17 yr (31). However, the exercise intensities in the latter studies (31, 33) were lower (60 and 55% VO2 peak, respectively) than in the present study (70% VO2 peak). As a result of their high rates of CHOexo oxidation, the relative provision of CHOexo to total energy expenditure in pre- and early pubertal boys, compared with adult men. Therefore, on the basis of our laboratory’s earlier observations (31–33) and the present findings (Table 3, Fig. 4), we propose that the utilization of CHOexo, as an energy source during exercise in pre- and early pubertal boys, compared with adult men. Therefore, on the basis of our laboratory’s earlier observations (31–33) and the present findings (Table 3, Fig. 4), we propose that the utilization of CHOexo, as an energy source during exercise in pre- and early pubertal boys, compared with adult men. Therefore, on the basis of our laboratory’s earlier observations (31–33) and the present findings (Table 3, Fig. 4), we propose that the utilization of CHOexo, as an energy source during exercise in pre- and early pubertal boys, compared with adult men. Therefore, on the basis of our laboratory’s earlier observations (31–33) and the present findings (Table 3, Fig. 4), we propose that the utilization of CHOexo, as an energy source during exercise in pre- and early pubertal boys, compared with adult men. Therefore, on the basis of our laboratory’s earlier observations (31–33) and the present findings (Table 3, Fig. 4), we propose that the utilization of CHOexo, as an energy source during exercise in pre- and early pubertal boys, compared with adult men. Therefore, on the basis of our laboratory’s earlier observations (31–33) and the present findings (Table 3, Fig. 4), we propose that the utilization of CHOexo, as an energy source during exercise in pre- and early pubertal boys, compared with adult men. Therefore, on the basis of our laboratory’s earlier observations (31–33) and the present findings (Table 3, Fig. 4), we propose that the utilization of CHOexo, as an energy source during exercise in pre- and early pubertal boys, compared with adult men. Therefore, on the basis of our laboratory’s earlier observations (31–33) and the present findings (Table 3, Fig. 4), we propose that the utilization of CHOexo, as an energy source during exercise in pre- and early pubertal boys, compared with adult men. Therefore, on the basis of our laboratory’s earlier observations (31–33) and the present findings (Table 3, Fig. 4), we propose that the utilization of CHOexo, as an energy source during exercise in pre- and early pubertal boys, compared with adult men. Therefore, on the basis of our laboratory’s earlier observations (31–33) and the present findings (Table 3, Fig. 4), we propose that the utilization of CHOexo, as an energy source during exercise in pre- and early pubertal boys, compared with adult men. Therefore, on the basis of our laboratory’s earlier observations (31–33) and the present findings (Table 3, Fig. 4), we propose that the utilization of CHOexo, as an energy source during exercise in pre- and early pubertal boys, compared with adult men. Therefore, on the basis of our laboratory’s earlier observations (31–33) and the present findings (Table 3, Fig. 4), we propose that the utilization of CHOexo, as an energy source during exercise in pre- and early pubertal boys, compared with adult men.

In summary, we have shown for the first time that healthy young boys oxidize relatively more CHOexo during 60 min of exercise than do healthy young men, under identical experimental conditions. Moreover, the boys maintained higher relative rates of Fattotal oxidation compared with the men, even when fed CHOexo. Lastly, the higher rate of CHOexo oxidation in the boys contributed proportionally more to the total energy expended. The boys’ preference for this endogenous fuel may result in an improved exercise performance and sparing of endogenous substrate, necessary for growth and development.

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EXOGENOUS CHO OXIDATION IN BOYS AND MEN