Submaximal Cardiovascular Responses to Exercise in Children: Treadmill Versus Cycle Ergometer

Kenneth R. Turley and Jack H. Wilmore

This study investigated whether cardiovascular responses at a given submaximal oxygen consumption (\( \dot{V}O_2 \), L \( \cdot \) min \(^{-1} \)) are different between the treadmill (TM) and cycle ergometer (CE). Submaximal cardiovascular measurements were obtained at three work rates on both the TM and CE in 7- to 9-year-old children (12 males and 12 females). Using regression analysis, it was determined that there were no differences between the TM and CE in cardiac output (L \( \cdot \) min \(^{-1} \)), stroke volume (SV, ml \( \cdot \) beat \(^{-1} \)) or heart rate (beats \( \cdot \) min \(^{-1} \)) at a given \( \dot{V}O_2 \) (L \( \cdot \) min \(^{-1} \)). There were differences in the total peripheral resistance (TPR, units) and arterial-venous oxygen difference (a-v\( \dot{O}_2 \) diff, ml \( \cdot \) 100 ml \(^{-1} \)) to \( \dot{V}O_2 \) (L \( \cdot \) min \(^{-1} \)) relationship. While there were statistically significant differences in TPR and a-v\( \dot{O}_2 \) diff between the two modalities, there was substantial overlap of individual values at any given submaximal \( \dot{V}O_2 \), thus the physiological significance is questionable. Hence, we conclude that in 7- to 9-year-old children there are no differences in submaximal cardiovascular responses between the CE and TM.

Exercise testing is commonly used in both clinical and healthy populations of children for a number of reasons (24), ranging from the identification of abnormal exercise responses to the establishment of baseline data for determining the effectiveness of an intervention program. When using exercise testing in the laboratory to study how the body adapts from rest to the increased demands of exercise, several different exercise modalities are used to provide accurate rates of work. In children, the two most commonly used modalities are the cycle ergometer (CE) and treadmill (TM) (14).

Of the studies that have used the TM with children, few have monitored cardiovascular responses to submaximal exercise. The majority of studies investigating cardiovascular responses to submaximal exercise in children have used the CE. In adults, significant differences in submaximal cardiovascular responses between the CE and TM have been reported (8). To our knowledge, no study has directly compared submaximal cardiovascular responses of children between the CE and TM. We recently reported significant differences in maximal work between the CE and TM in

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7- to 9-year-old children (21), but whether differences exist in submaximal cardiovascular responses between the CE and TM in young children is unknown. In previous publications we described boy-versus-girl differences (22) and adult-versus-child differences (23) in submaximal cardiovascular responses to exercise. In the present report we describe information that provides important data regarding submaximal cardiovascular responses in CE versus TM exercise in 7- to 9-year-old children.

Methods

Subjects and Design

Twenty-four healthy 7- to 9-year-old children (12 boys and 12 girls) agreed to participate in this study. Written informed consent was obtained from each of the children and their parents. After the children had completed all but their final testing day, they were asked to sign a separate consent form specifically for a blood draw. The separate consent form for the blood draw was used so that the children would not be discouraged from participating in the study based solely on their fear of having their blood drawn. The study design and consent forms had been previously approved by The University of Texas at Austin Institutional Review Board. All subjects were active but not participating in formal training or organized sports.

All testing was conducted in the Human Performance Laboratory at The University of Texas at Austin. Each subject visited the laboratory six times. During the first visit, maximal oxygen consumption (VO_max) was determined (random draw of either TM or CE), anthropometric measurements were obtained, and a 10-min accommodation period on the TM (5 min at both 3.0 and 5.0 miles per hour [mph]) was provided. On the second visit, a submaximal steady-state 4.0-mph walk on the TM and a second maximal test on the ergometer not used in the first test were conducted. From the results of pilot work, we found that children were just able to complete steady-state cardiovascular measurements on the TM when they exercised at both 3.0 and 5.0 mph on the same day. Hence, the children completed the 4.0-mph portion of their submaximal TM test once, on their second visit. On each of the next four visits, one of four randomized submaximal steady-state exercise tests was conducted (two CE and two TM). The children exercised at three different submaximal rates of work on each ergometer.

On the last visit, a blood sample was drawn immediately following exercise (optional) to determine hemoglobin concentration ([Hb]) for use in the calculation of cardiac output (Q). Testing for each subject was conducted within a 2- to 4-week period, with a minimum of 24 hr between tests.

Maximal Tests

Maximal tests were conducted on a motor driven TM (Quinton Q65) and on an electronically braked CE (Ergoline 800S, SensorMedics). Prior to the commencement of the maximal tests, the children were allowed a 3- to 5-min warm-up, after which the protocol began. For safety purposes, a spotter was positioned behind the children during maximal TM testing. Maximal tests on both the TM and CE were continuous incremental protocols (23).

During maximal tests, the subjects exercised to volitional fatigue. Tests were considered maximal when at least two of the following criteria were achieved: (a) failure to maintain the work rate, (b) respiratory exchange ratio (RER) ≥ 1.00, and (c) maximal heart rate (HR) ≥ 95% of age-predicted maximum. Since it has re-
recently been reported that a plateau in \( \text{VO}_2 \) is seldom achieved in children (2, 18, 19), attainment of a plateau was not used as a criterion for \( \text{VO}_{2\text{max}} \). If two or more of these criteria were not achieved, a second maximal test was performed.

**Submaximal Tests**

Prior to the commencement of both the TM and CE submaximal tests, the children were allowed a 3- to 5-min warm-up period. Submaximal exercise tests on the TM were at 3.0, 4.0, and 5.0 mph. The 4.0-mph work rate was only completed once. One boy did not do the 4.0-mph work rate. The TM was calibrated during each submaximal test at each speed to insure that the appropriate speed was maintained.

On the CE, children exercised at 20, 40, and 60 W cycling at 65 ± 5 revolutions per minute (rpm). One girl was not able to complete the 60-W work rate. The CE was calibrated daily. Ad libitum water consumption was allowed during all submaximal tests.

Submaximal cardiovascular and metabolic data were collected during steady-state exercise. Steady-state was defined as an HR response within ±5 beats·min⁻¹, and three consecutive 20-s values for both \( \text{VO}_2 \) and carbon dioxide production (\( \text{VCO}_2 \)) within ±10%. Once steady-state had been achieved, blood pressure (BP), HR, \( \text{VO}_2 \), and \( \dot{Q} \) measurements were obtained in duplicate. The HR and \( \text{VO}_2 \) used as steady-state values were one-minute averages taken just prior to the carbon dioxide (\( \text{CO}_2 \)) rebreathing maneuver for determination of \( \dot{Q} \). A 3- to 5-min rest period was allowed between each work rate and between duplicate measurements at the highest work rate when necessary.

**Measurements**

**Anthropometry.** Height, weight, and skinfold thicknesses were measured during the subject's first visit to the laboratory. Relative body fat was estimated using skinfold measurements and the Slaughter et al. equations (9, 20). Fat mass (FM) was determined by (relative body fat [%] · body weight [kg])/100. Fat free mass (FFM) was determined by body weight (kg) – FM. Body surface area (BSA, m²) was calculated using the Haycock et al. formula (7). Body mass index (BMI) was calculated by dividing body weight (kg) by stature squared (m²).

**Metabolic.** Expired gases during both the maximal and submaximal tests were collected and analyzed using a SensorMedics 2900 metabolic cart (Yorba Linda, California). The gas analyzers were calibrated with gases of known concentration, and the flow meter with a known volume of air, both before and after each test. \( \text{VO}_{2\text{max}} \) and RERmax were the average of the two highest consecutive 20-s values.

**Cardiovascular.** HR was monitored and recorded with a Polar HR monitor. BP was measured with a Colin Model STBP-780 semiautomated BP measurement device (Colin Medical Instruments Corp., San Antonio, TX). The BP cuff was selected so that the cuff bladder width was ~40% of the subject's upper arm circumference measured at mid-bicep (6, 10)

Cardiac output was measured indirectly using the \( \text{CO}_2 \)-rebreathing equilibration method (3) as described by Jones (12, 13). The rebreathing system was modified for children. A 2600 series Hans Rudolph two-way valve (48 ml dead space) was connected to an 8200 series Hans Rudolph rebreathing switching system and a 3-L bag was used for \( \text{CO}_2 \)-rebreathing. The downstream correction was applied in order
to adjust the venous blood CO$_2$ levels for the alveolar to blood CO$_2$ partial pressure difference (11, 17). The CO$_2$ dissociation curve described by Jones and Campbell (11), as adapted from McHardy (15), was used to convert the partial pressures of CO$_2$ to content of CO$_2$. This content was corrected for the affect of hemoglobin concentration ([Hb]) on CO$_2$ carrying capacity of the blood (11, 15). The [Hb] used for the children who did not consent to having their blood drawn was the average value obtained in this study for their gender. Due to technical difficulties, blood was obtained from only 17 of the 21 children who consented to have their blood drawn.

Stroke volume (SV, ml) was calculated as $Q$ (ml)/HR (beats · min$^{-1}$). Mean blood pressure (MBP, mmHg) was determined as $\left[\frac{\text{systolic BP} + (2 \times \text{diastolic BP})}{3}\right]$. Total peripheral resistance (TPR, units) was calculated as MBP/$Q$. $VO_2$ was divided by $Q$ to calculate a-vO$_2$ diff (ml · 100ml$^{-1}$).

**Hemoglobin.** Blood for [Hb] assessment was collected in the sitting position immediately following the last submaximal exercise test using a venipuncture in the antecubital vein. [Hb] was measured in quadruplet by the cyanmethemoglobin method, with an average of the four measurements used as the [Hb]. Blood was drawn immediately after exercise to most accurately adjust $Q$ for the change in [Hb] during exercise.

**Analysis**

We have reported in a previous paper (22) that there were minimal differences in submaximal cardiovascular responses between the boys and girls in this study; thus, the data of the boys and girls were combined. Differences between CE and TM $VO_2$ max values were determined with a repeated measures ANOVA. For comparisons of the submaximal exercise cardiovascular variables between the CE and TM, the mean of the values collected on the first day and second day for both the TM and CE was used. Significant differences of slopes and intercepts of the cardiovascular variables relative to $VO_2$ ($L$ · $min^{-1}$) between the CE and TM were determined by seemingly similar regression analysis (SAS, UNIX System), which assumes similar errors between the regression lines. All significant differences are at the $p \leq 0.05$ level unless stated otherwise.

**Results**

The physical characteristics of the subjects are presented in Table 1. The $VO_2$ max data from both the TM and CE are presented in Table 2. $VO_2$ max was significantly higher on the TM than the CE, regardless of how it was expressed ($L$ · $min^{-1}$ or ml · kg$^{-1}$ · $min^{-1}$). Further, $VO_2$ max expressed in both $L$ · $min^{-1}$ ($r = .95$) and ml · kg$^{-1}$ · $min^{-1}$ ($r = .84$) was closely related between the TM and CE.

In this study, in order to determine if there were significant differences in cardiovascular responses between the CE and TM at equivalent $VO_2$ ($L$ · $min^{-1}$) levels, the regression lines of each of the cardiovascular variables to $VO_2$ ($L$ · $min^{-1}$) were statistically compared. The comparisons of the CE and TM regression lines for each of the cardiovascular variables are presented in Figures 1–5. The legend for each of the figures presents the regression equation and statistical significance of differences, if any, in slopes and intercepts of the regression lines between the CE and TM.

There were no significant differences between the CE and TM in slopes or intercepts for $Q$ (Figure 1), HR (Figure 2) or SV (Figure 3) relative to $VO_2$ ($L$ · $min^{-1}$). The intercept of the TPR (Figure 4) to $VO_2$ ($L$ · $min^{-1}$) relationship was significantly
Table 1  Physical Characteristics of the Subjects

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<thead>
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<th>Variable</th>
<th>M</th>
<th>SD</th>
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</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>9.0</td>
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<tr>
<td>Height (cm)</td>
<td>133.5</td>
<td>6.3</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>29.0</td>
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<tr>
<td>Fatty mass (kg)</td>
<td>4.9</td>
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<tr>
<td>Body fat (%)</td>
<td>16.3</td>
<td>4.3</td>
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<tr>
<td>Fat free mass (kg)</td>
<td>24.2</td>
<td>3.1</td>
</tr>
<tr>
<td>Body mass index (kg · m⁻²)</td>
<td>16.2</td>
<td>1.7</td>
</tr>
<tr>
<td>Body surface area</td>
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<td>0.10</td>
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<tr>
<td>Hemoglobin (g · dl⁻¹)</td>
<td>13.3</td>
<td>0.7</td>
</tr>
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</table>

Note. N = 24.

Table 2  Treadmill and Cycle Ergometer Maximal Data

<table>
<thead>
<tr>
<th>Variable</th>
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<th>SD</th>
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<tr>
<td>Treadmill</td>
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<td></td>
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<tr>
<td>(VO_{2,\text{max}}) (L · min⁻¹)</td>
<td>1.55*</td>
<td>0.22</td>
</tr>
<tr>
<td>(ml · g⁻¹ · min⁻¹)</td>
<td>53.7*</td>
<td>4.9</td>
</tr>
<tr>
<td>HR (beats · min⁻¹)</td>
<td>201*</td>
<td>10</td>
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<tr>
<td>RER</td>
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<td>0.06</td>
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<tr>
<td>Cycle ergometer</td>
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<tr>
<td>(VO_{2,\text{max}}) (L · min⁻¹)</td>
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<td>0.24</td>
</tr>
<tr>
<td>(ml · kg⁻¹ · min⁻¹)</td>
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<td>HR (beats · min⁻¹)</td>
<td>197</td>
<td>9</td>
</tr>
<tr>
<td>RER</td>
<td>1.10</td>
<td>0.06</td>
</tr>
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</table>

Note. \(VO_{2,\text{max}}\) = maximal oxygen consumption; HR = heart rate; RER = respiratory exchange ratio.

*Significantly different \((p \leq .05)\) from cycle ergometer.

higher and the slope significantly steeper on the TM. Lastly, the intercept of a-v\(VO_{2}\) diff (Figure 5) relative to \(VO_{2}\) (L · min⁻¹) was significantly lower and the slope significantly steeper on the CE.

Discussion

The results of this study indicate that the cardiovascular response to submaximal exercise in 7- to 9-year-old children is similar between the CE and TM at equiva-
Figure 1 — The cardiac output ($Q$) to $VO_2$ relationship for both the cycle ergometer and treadmill.

Figure 2 — The heart rate (HR) to $VO_2$ relationship for both the cycle ergometer and treadmill.

Lent $VO_2$ ($L \cdot min^{-1}$) levels, $Q$, HR, and SV were nearly identical at a given $VO_2$ when comparing the CE and TM. TPR was higher at the lower $VO_2$ ($L \cdot min^{-1}$) levels and decreased to a significantly greater degree with increasing work rate on the TM. Further, $a-vO_2$ diff was less at the lower $VO_2$ ($L \cdot min^{-1}$) levels, and it increased to a greater degree with increasing work rate on the CE.
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Figure 3 — The stroke volume (SV) to \( \dot{V}O_2 \) relationship for both the cycle ergometer and treadmill.

![Graph showing SV vs. VO2 for cycle and treadmill](image)

Figure 4. Total peripheral resistance (TPR) on \( \dot{V}O_2 \) for both the cycle ergometer and treadmill. Included in the legend is the regression equation used in the statistical analysis. The parentheses represent a summary of the statistical analysis, where \( a \) indicates the intercept is significantly different \( (p \leq .05) \) from treadmill, and \( b \) indicates the slope is significantly different \( (p \leq .05) \) from treadmill.

![Graph showing TPR vs. VO2 for cycle and treadmill](image)

To our knowledge, this is the first study that has compared submaximal cardiovascular responses between the CE and TM in children that were measured on both modalities. In adults, there have been several studies that have examined the differences in cardiovascular responses between the TM and CE during both submaximal (8) and maximal or near maximal rates of work (4, 8, 16). Hermansen
Figure 5. Arterial–venous oxygen difference (a-vO₂ diff) on VO₂ for both the cycle ergometer and treadmill. Included in the legend is the regression equation used in the statistical analysis. The parentheses represent a summary of the statistical analysis, where a indicates the intercept is significantly different (p ≤ .05) from treadmill, and b indicates the slope is significantly different (p ≤ .05) from treadmill.

e.t al. (8) found that at a given submaximal VO₂ in 13 men (ages 19–34 years), HR was 6–10 beats · min⁻¹ higher on the CE while Q was the same for both modalities. Thus, SV was significantly (p < .05) higher (5%) on the TM.

In children, Anderson and Godfrey (1) compared the cardiovascular responses of boys and girls during TM exercise to the cardiovascular responses of a different sample of boys and girls during CE exercise obtained in a companion study (5). They reported that (a) Q was similar between the two modalities for the same absolute VO₂ at lower work rates, yet slightly lower at the higher work rates on the TM; (b) SV was nearly the same; and (c) HR was slightly lower on the TM. The lower HR on the TM in children reported by Anderson and Godfrey (1) is in agreement with the adult data of Hermansen et al. (8). On the other hand, the similar SV between the TM and CE is in contrast to the significantly higher SV on the TM versus the CE reported in adults by Hermansen (8). Nonetheless, Anderson and Godfrey (1) concluded that the differences in cardiovascular responses between the TM and CE in children are the same as the differences reported in adults. It is important to note that their data comparing the TM and CE were not collected on the same group of children in the same study, and their values were not analyzed statistically.

Our results in children are in contrast to those of Anderson and Godfrey (1), as we found submaximal cardiovascular responses are the same at equivalent VO₂ (L · min⁻¹) levels for the CE and TM. Further, the significant differences we found in the intercepts for both TPR and a-vO₂ diff relative to VO₂ are likely due to the significantly steeper slopes of these relationships. From Figures 4 and 5, it is evident that there is a great deal of overlap of TPR and a-vO₂ diff values at any given VO₂ on the CE and TM; thus, the physiological significance of these statistically significant differences is questionable.
The reason for the differences between our results (similar HR and SV) and those of Hermansen et al. (8) are uncertain. One possible explanation for the discrepancy between our child data and the Hermansen et al. (8) adult data is that the cardiovascular system of children responds differently at a given VO$_2$ on a given exercise modality (23). This is not the case, though, as both our child and unreported adult (Turley and Wilmore, unpublished) submaximal cardiovascular responses were essentially the same when comparing the TM and CE.

Another possible explanation for the discrepancy in results is that 9 of the 13 male subjects in the Hermansen et al. study (8) were well trained. It may be that the more highly trained the subject, the greater the difference in submaximal cardiovascular responses between different exercise modalities due to the “specificity of training principle” (25).

Furthermore, Hermansen et al. (8) and others (25) suggest that blood flow to active muscle during cycling may be restricted due to muscle contraction, thus altering SV and HR relative to TM exercise. The reason we did not see these differences in SV and HR in our children may be related to the size of the muscle mass recruited during exercise. We have suggested (23) that to do the same absolute rate of work (VO$_2$, L · min$^{-1}$), children use a smaller muscle mass compared to adults. The amount of muscle used by the children may be too small to elicit the differences in HR and SV.

Our finding of similar a-VO$_2$ diff and TPR to VO$_2$ relationships between the CE and TM in the children was also reported by Hermansen et al. (8) in adults. They attributed the similar a-VO$_2$ diff to a similar distribution of blood flow and oxygen utilization when comparing CE and TM exercise. They further stated that there does not seem to be a large difference in muscle mass recruitment between the two modalities. This is supported by our findings of similar submaximal cardiovascular responses for the CE and TM.

Thus we conclude from this study that in healthy 7- to 9-year-old children there are no differences in submaximal cardiovascular responses between the CE and TM, and, though there were significant differences in TPR and a-VO$_2$ diff between the two modalities, there was substantial overlap of individual values at any given VO$_2$ level. Lastly, the similarity in submaximal cardiovascular response in the children between the CE and TM demonstrates that either can be used to accurately obtain cardiovascular measurements in children, and other factors such as space availability, cost, portability, and study design should be used to determine which exercise modality is most appropriate.

References

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