ABSTRACT

The purpose of this study was to identify and quantify the magnitude of the slow component of VO₂ (SC) in children during running exercise, performed at heavy intensity domain (75%Δ), using two different mathematical models: a) three-exponential model and; b) ∆VO₂ 6-3 min. Eight healthy male children (11.92 ± 0.63 years; 44.06 ± 13.01 kg; 146.63 ± 7.25 cm; and sexual maturity levels 1 and 2), not trained, performed in different days the following tests: 1) incremental running treadmill test to determine the peak oxygen uptake (VO₂peak) and the lactate threshold (LT); and 2) two transitions from baseline to 75%Δ [75%Δ = LT + 0.75 x (VO₂ peak - LT)] for six minutes on treadmill. The SC was determined by two models: a) three-exponential model (Exp3); and b) the VO₂ difference between the sixth and the third exercise minute (ΔVO₂ 6-3 min). The SC was expressed as the absolute (ml/min) and percent contribution (%) to the total change in VO₂. The SC values determined by model Exp3 (129.69 ± 75.71 ml/min and 8.4 ± 2.92%) and ΔVO₂ 6-3 min (68.69 ± 102.54 ml/min and 3.6 ± 7.34%) were significantly different. So, the SC values in children during running exercise performed at heavy intensity domain (75%Δ) are dependent of the analysis model (Exp3 x ΔVO₂ 6-3 min).

INTRODUCTION

The respiratory system behavior observed during the resting-exercise transition presents variations dependent on the exertion intensity applied. In exercises of steady loads with intensities above the lactate threshold (LT), characterized from this point on as heavy exercise, we may observe an additional cost of the oxygen consumption (VO₂), which causes a delay in reaching a new steady state for this variable. Such overlapping of the respiratory component is called slow component (SC) of the VO₂.

The SC of the VO₂ has its occurrence and magnitude very diverse in relation to the type of exercise performed. The majority of work conducted with the purpose to verify and quantify the SC gives priority to exercise performed in cycle ergometer. However, the found indices in this ergometer in adults are always higher than the ones obtained during running exercise. Besides the theoretical implications, the comprehension and determination of the SC may be extremely important in the exercise prescription, once some authors have been proposing that the maximal tolerance of the performed exertion above the lactate steady maximal phase or critical power (~80-85%VO₂ max), may be dependent on the SC behavior. Among other applications, this aspect may be important for the exercise prescription in children and adolescents, since several studies have verified that the improvement in the aerobic ability in this population seems to be dependent on the utilization of exercise intensities (> 80-85%VO₂ max) where SC may be present.

Nonetheless, few studies have analyzed the occurrence of SC and the factors that may determine it in children and adolescents. Armon et al. verified the lack of occurrence of SC of VO₂ in approximately 50% of the children analyzed in his study. Among the ones who presented the phenomenon, a smaller magnitude in relation to adults was verified for indices expressed both in l/min and in ml/kg/min, besides not demonstrating increase with the exertion intensity. Armon et al. suggested that the lack of occurrence of SC of VO₂ is due to the fact that children present lower concentrations of lactate in relation to adults. Similar results were obtained by Williams et al. during exercise on treadmill. In this study, where the exercise was performed at 50%Δ (50% of the difference between the LT and the VO₂peak), the magnitude of the SC expressed in absolute (115.9 ± 7 ml/min vs. 18.6 ± 18.9 ml/min) and relative values (8.3 ± 1.0% vs. 0.9 ± 1.2%) to the increase of the VO₂ for the intensity of performed exercise (gain), was significantly higher in men than in boys, respectively. The adults also obtained higher alterations in the blood lactate concentrations at the end of the exercise. However, Fawkner and Armstrong verified relative values of SC (~10%) fairly higher than the ones in the study by Williams et al. in boys (10.6 years) during exercise performed at 40%Δ in cycle ergometer. According to what has been discussed before, such antagonistic data could be explained, at least partly, by the different types of exercises that were analyzed in the study by Williams et al. and Fawkner and Armstrong (running x cycling, respectively).

Some researchers have used a criterion that considers a strict time interval in order to estimate the magnitude of the SC with the purpose to determine and quantify this variable. Specifically, the difference of the VO₂ between the sixth minute and the third minute (∆VO₂ 6-3 min) of exercise is used as index for that matter. In this criterion, it is assumed that the VO₂ would only reach the index corresponding to the load after three minutes of exercise. Nonetheless, mathematical analyses which used two or three exponential terms have demonstrated that the SC of the VO₂ may initiate before the third minute of exercise. Such fact leads to a conclusion that other methods of verification and quantification are needed not to underestimate its value, considering other respiratory behavior characteristics during the resting-exercise transition of steady intensities above the LT. These different criteria could partly justify the antagonistic data obtained by Armon et al. and Fawkner and Armstrong during exercise in cycle ergometer. Thus, it is possible to raise the hypothesis that not only the type of exercise, but also the applied criterion, may influence in the characterization of the slow component of VO₂ in children. Despite of that,
one may consider that studies that have analyzed the influence of different criteria in the calculation of the SC of VO\textsubscript{2} in children during running performed at high intensity domain were not found (> LT). Therefore, the aim of this study was to verify and quantify the magnitude of the slow component of VO\textsubscript{2} in children submitted to running exercise on treadmill, with steady loads of intensity above the LT (75%Δ), using for that matter two models of analysis: a) mathematical model with three exponential terms and; b) ∆VO\textsubscript{2} 6-3 min model.

METHODS

Subjects

Eight male children apparently healthy participated in the study (age = 11.92 ± 0.63 years; body weight = 44.06 ± 13.01 kg; height = 146.63 ± 7.25 cm), with sexual maturation 1 and 2 (pubic hair growth) determined according to the model proposed by Tanner\textsuperscript{14}. It was verified through a questionnaire that the children were regularly engaged in School Physical Education classes, besides performing other practice with working load of approximately 3 h/week. However, none of the participants were inserted in competitive training of any kind. Each participant was informed about the experiment procedures and its implications, and signed the participation consent form with his legal responsible agreement. The protocol was approved by the Research Ethics Committee of the institution where the experiment was conducted (Document CEP 22/2004).

Experimental outlining

The children paid three visits to the Laboratory of Evaluation of Human Performance, Unesp – Rio Claro, SP. The first visit had the purpose to conduct a preliminary test so that the children could adapt to the ergometer and the protocol to be used, as well as to measure the body weight, height and determine the maturational status. The second visit had the purpose to conduct an incremental test in order to determine the LT and the VO\textsubscript{2peak}. The third visit had the aim to conduct the steady load tests for the characterization of the kinetics of the VO\textsubscript{2} during heavy exercise (75%Δ).

Incremental test

The incremental test was performed on treadmill (Imbramed Millenium Super ATL, Porto Alegre, Brazil). The initial velocity was of 5 km/h with increases of 1 km/h at every 3 minutes, being kept a constant inclination equivalent to 1% during the entire test. All the stages were followed by 30 seconds of recovery. The test was kept until participants’ exhaustion, who were verbally encouraged to keep exercising as far as possible. The cardiorespiratory variables were measured through a gases analyzer (Cosmed K4, Rome, Italy), collecting data breath after breath. The systems of analysis of O\textsubscript{2} and CO\textsubscript{2} were calibrated using the room air and a gas with physiological limits (12). The slow component was calculated in relative biological limits (12). The slow component breadth was determined as the increase of VO\textsubscript{2} at the end of phase 1 (A\textsubscript{0}) and the breadth of phase 2 (A\textsubscript{1}). The phase 1 term finished at the phase 2 beginning (i.e., at TA\textsubscript{1}) and the index for time (A\textsubscript{1}) was pointed out.

The VO\textsubscript{2} at the end of phase 1 (A\textsubscript{0}) and the breadth of phase 2 (A\textsubscript{1}) were added in order to calculate the breadth of phase 2 (A\textsubscript{2}). An additional measurement of the slow component was considered as the difference in the VO\textsubscript{2} between the indices of the sixth (mean index between 5.75 and 6.0 min) and third minute of exercise (mean index between 2.75 and 3.0 min of exercise) (∆VO\textsubscript{2} 6-3 min).

Statistical analysis

The indices are presented as mean ± standard deviation. The Wilcoxon test was used in order to compare the SC indices of VO\textsubscript{2} (absolute and relative) by the two different methods, adopting significance level p ≤ 0.05.

RESULTS

In table 1 the mean indices ± SD of the VO\textsubscript{2}peak and its respective velocity (vVO\textsubscript{2}peak); of the VO\textsubscript{2} corresponding to the LT intensity; of the maximal heart rate (HR\textsubscript{max}) and of the peak lactate obtained during the incremental test are found. In table 2 the mean ± DP indices of the velocity related to 75%Δ and its respective percentage of the VO\textsubscript{2}peak; of the HR (mean of
the last minute of each transition) and of the Δ[La] obtained during the steady intensity test, are found.

The kinetics parameters of the VO₂, derived from the analysis with three exponential terms are found in table 3.

### TABLE 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>VO peak (ml/kg/min)</th>
<th>vVO peak (Km/h)</th>
<th>LT (ml/kg/min)</th>
<th>LT (%VO peak)</th>
<th>HR (bpm)</th>
<th>Peak lactate (mM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>45.90</td>
<td>10.37</td>
<td>36.10</td>
<td>77.92</td>
<td>192.38</td>
<td>5.57</td>
</tr>
<tr>
<td>SD</td>
<td>7.12</td>
<td>1.50</td>
<td>9.02</td>
<td>11.08</td>
<td>13.30</td>
<td>2.93</td>
</tr>
</tbody>
</table>

### TABLE 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean ± SD indices of the velocity and percentage of the %VO peak (ml/min) referring to 75%Δ</th>
<th>Mean ± SD indices of the heart rate (HR) and the variation (initial-final index) of the lactate (Δ[La]) in the steady load test</th>
</tr>
</thead>
<tbody>
<tr>
<td>75%Δ (km/h)</td>
<td>9.20 ± 2.70</td>
<td>Mean ± SD indices of the heart rate (HR) and the variation (initial-final index) of the lactate (Δ[La]) in the steady load test</td>
</tr>
<tr>
<td>75%Δ (%VO peak)</td>
<td>94.4 ± 3.70</td>
<td>Mean ± SD indices of the heart rate (HR) and the variation (initial-final index) of the lactate (Δ[La]) in the steady load test</td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>181.63 ± 10.03</td>
<td>Mean ± SD indices of the heart rate (HR) and the variation (initial-final index) of the lactate (Δ[La]) in the steady load test</td>
</tr>
<tr>
<td>Δ[La] (mM)</td>
<td>2.19 ± 1.34</td>
<td>Mean ± SD indices of the heart rate (HR) and the variation (initial-final index) of the lactate (Δ[La]) in the steady load test</td>
</tr>
</tbody>
</table>

### TABLE 3

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Model with three exponential terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO basis (ml/min)</td>
<td>360.0 ± 100.0</td>
</tr>
<tr>
<td>A₁' (ml/min)</td>
<td>350.49 ± 135.85</td>
</tr>
<tr>
<td>A₂' (ml/min)</td>
<td>1332.7 ± 394.50</td>
</tr>
<tr>
<td>T₂' (sec)</td>
<td>20.64 ± 4.17</td>
</tr>
<tr>
<td>A₃' (ml/min)</td>
<td>129.28 ± 29.34</td>
</tr>
<tr>
<td>t₁ (sec)</td>
<td>250.03 ± 84.43</td>
</tr>
<tr>
<td>% A₂'</td>
<td>8.49 ± 2.92</td>
</tr>
<tr>
<td>VO final (ml/min)</td>
<td>1462.72 ± 457.22</td>
</tr>
</tbody>
</table>

To our knowledge, this study was the first to identify that the model of analysis (mathematical model with three exponential terms x ΔVO₂, 6-3 min model) in children, modifies the characterization of the SC, with the ΔVO₂, 6-3 min model probably underestimating its magnitude. Such behavior may be clearly explained when it is verified that the beginning of the SC occurred after approximately 2 minutes of exercise (TD2 = 129 sec), before hence, the time used in the ΔVO₂, 6-3 model.

The SC indices found in our study cannot, in principle, be directly compared with the ones obtained in other studies conducted with children running. Besides the differences in models of analysis, no data of the SC were found in the intensity analyzed in this study (75%Δ). In adults, when using the same exercise mode (running x cycling), Billat et al.(2) characterized the SC as the difference in VO₂ between the third and sixth minute of exercise of heavy intensity, assuming that close and from that time, it is possible to observe the appearance of the SC. Some studies used hence, the criterion of time interval 6-3 minutes in order to estimate the magnitude of the SC.(10-11) Nonetheless, mathematical models more expressive have demonstrated that the SC of VO₂ begins before the third minute of exercise, leading to believe that the determination through the ΔVO₂, 6-3 minutes method may underestimate the real indices of this parameter in adults.(12-13)

The aim of this study was to verify and quantify the magnitude of the SC of VO₂ in children submitted to running exercises on treadmill, with steady loads of intensity above the LT (75%Δ), using for this matter two models of analysis: a) mathematical model with three exponential terms; and b) ΔVO₂, 6-3 min model. Our main finding was that the SC indices, in the studied conditions, are dependent on the model of analysis used (exponential model with three terms x ΔVO₂, 6-3 min). Thus, children submitted to steady loads exertion in running with intensities above the LT present the occurrence of overlapping of oxygen consumption (SC). Although the indices found can be specific and characteristic of this age group and the exercise mode, there is a clear occurrence of this respiratory phenomenon, generating hence a delay in reaching a new steady status of this behavior in the intention of fulfilling the needs imposed by the exercise.

Our results corroborate the ones found by Fawkner, and Armstrong(9) who using an exponential model with two terms, clearly identified the occurrence of the SC (100 ± 60 ml/min and 9.4 ± 4.6%) in children with ages between 10 and 11 years, submitted to a heavy exercise protocol of steady loads in cycle ergometer. On the other hand, our results are different from the ones obtained by Armon et al.(10) who verified the lack of occurrence of the SC of VO₂ in the majority of the children analyzed during exercise of steady load in cycle ergometer. Armon et al.(7) used in their study a model of exponential analysis in order to determine the SC, considering that this model presented linear relation fairly consistent (73%) with the analysis of the increase of VO₂ between the third and sixth minute of exercise. Thus, one may initially raise the hypothesis that the disagreements between the studies conducted with children of 10 to 11 years are more due to the model of analysis of the SC than to the exercise mode (running x cycling).

The kinetics parameters of the VO₂, derived from the analysis with three exponential terms are found in table 3.

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The kinetics parameters of the VO₂, derived from the analysis with three exponential terms are found in table 3.

The absolute (ml/min) and relative (%) indices of the SC obtained in the two methods of analysis are presented in figure 2. The absolute and relative indices of SC were significantly lower through the ΔVO₂, 6-3 method than through the method with three exponential terms.
increased significantly between the 10.6 and 12.6 years during heavy exercise (40% Δ) performed in cycle ergometer. Interestingly, some studies conducted in adults with different aerobic training levels, have verified that the SC (absolute and relative) is higher during heavy exercise in cycling than in running²⁻⁴. Therefore, one may also hypothesize that the SC seems to be dependent on the interaction between the exercise type and the chronological age.

Some studies mention that the occurrence and the magnitude of the SC would be related to the accumulation of blood lactate during heavy exercise¹⁵⁻¹⁶. Others verified low correlation between the variables associated to SC and blood lactate during exercise on treadmill and bicycle, though². In children, one of the hypothesis pointed for the lack and/or little magnitude of the SC of VO₂ during heavy exercise, would be due to reason that they present lower concentrations of blood lactate in relation to adults. Nevertheless, our indices of Δ[La] (2.02 ± 1.24 mM) are lower than the ones found by Carter et al.⁴ in adults (4.0 ± 0.5 mM), suggesting that the relation between accumulation of lactate and SC may not exist, once the relative indices of SC were similar between the studies.

Therefore, we conclude that there is occurrence of SC of VO₂ in children submitted to running exercise on treadmill under heavy intensity; being these indices similar to the ones found in exercised adults under the same conditions. Concerning the comparison of the two methods of analysis (mathematical model with three exponential terms and ΔVO₂ 6-3 min model), we observed significant statistical differences for the SC indices, leading us to agree with the existing literature which mentions understimation of these indices when simpler models are used for analysis.

All the authors declared there is not any potential conflict of interests regarding this article.

REFERENCES


