Achievement of $\dot{V}O_2\text{max}$ Criteria in Adolescent Runners: Effects of Testing Protocol

Anita M. Rivera-Brown, Miguel A. Rivera, and Walter R. Frontera

This study examined the effects of three testing protocols on the frequency of achievement of $\dot{V}O_2\text{max}$ criteria in 13 male adolescent long-distance runners. All subjects completed the modified Taylor (T), Bruce (B), and Taylor intermittent (TI) running protocols on a treadmill to volitional fatigue. The criteria for $\dot{V}O_2\text{max}$ were (a) respiratory exchange ratio (R) $\geq$ 1.0, (b) heart rate (HR) $\geq$ 95% predicted max, and (c) increase in $\dot{V}O_2$ $\leq 2.1 \text{ ml.kg}^{-1}.\text{min}^{-1}$ with an increase in workload. A plateau was identified in 54%, 39%, and 85% of the subjects during the T, B, and TI protocols, respectively ($p < .05$). $\dot{V}O_2$ at exhaustion was similar during all protocols ($T = 70.8 \pm 4.1$, $B = 71.4 \pm 3.5$, $TI = 69.6 \pm 5.0 \text{ ml.kg}^{-1}.\text{min}^{-1}; p > .05$). The data suggest that the characteristics of a protocol can determine the frequency of a plateau achievement but have no effect on the attainment of the R or HR criteria. $\dot{V}O_2$ during running exercise to volitional fatigue is independent of testing protocol.

Evaluating the effects of aerobic training programs on the cardiorespiratory capacity of adolescents requires the identification of precise initial and follow-up maximal oxygen consumption ($\dot{V}O_2\text{max}$) values. The measurement of $\dot{V}O_2\text{max}$ entails a progressive exercise test to volitional fatigue. Established criteria are used to determine if a subject has achieved a true maximal effort (3). A plateau in $\dot{V}O_2$ has been identified as the most objective criterion for establishing a valid $\dot{V}O_2\text{max}$ value in adults, children, and adolescents (22). Other valid indicators of the limits of the cardiorespiratory system commonly utilized (2, 14, 15, 20) as criteria for $\dot{V}O_2\text{max}$ in adolescents are a respiratory exchange ratio (R) $\geq 1.0$ and a heart rate (HR) $\geq 95\%$ of the predicted maximal or a leveling off at peak exercise. Although the R and HR criteria are used in conjunction with the plateau criterion, most investigations establish a $\dot{V}O_2\text{max}$ value based solely on the latter. If a plateau is not observed, the highest $\dot{V}O_2$ value is considered $\dot{V}O_2$ peak and not $\dot{V}O_2\text{max}$.

A low rate of achievement of the plateau criterion has been reported in adolescent untrained and active subjects (1, 2, 6, 7, 15, 16, 20). It is possible that a true $\dot{V}O_2\text{max}$ value is not easily identified in children or adolescents because

Anita M. Rivera-Brown, Miguel A. Rivera, and Walter R. Frontera are with the Center for Sports Health and Exercise Sciences, Albergue Olímpico, P.O. Box 2004, Salinas, PR 00751.
it is based on a phenomenon that has not been proven to occur consistently in these age groups. Recently, we reported that only 11.5% of a group of very active adolescents who participated in regular exercise programs showed a plateau in $\dot{V}O_2$, and we proposed that age-specific criteria for $\dot{V}O_2$ max be developed that do not include a plateau in $\dot{V}O_2$ (16).

In adolescents, the reasons for the low frequency of achievement of this criterion have not been identified or explained adequately. Several studies have examined differences between plateau achievers and nonachievers in an attempt to identify characteristics that could be associated with the ability to reach a plateau (2, 6, 7). These studies have found no differences between the two groups in postexercise blood lactate levels, peak $\dot{V}O_2$, and peak $R$. Only one study reported a 4% higher $\dot{V}O_2$ max in plateau achievers (15). We recently reported no differences on anthropometrical characteristics, $\dot{V}O_2$, and $R$ during maximal exercise, and isokinetic power of the knee extensor and knee flexor muscle groups between adolescents who achieved a plateau and those who did not (16). Other factors that may influence the achievement of a plateau in $\dot{V}O_2$ during progressive treadmill exercise, such as training status and testing protocol, have not been adequately studied in adolescents.

Many studies reporting the frequency of achievement of $\dot{V}O_2$ max criteria in adolescents have used various continuous and intermittent running protocols. These differ from the original protocols used with adults to develop $\dot{V}O_2$ max criteria in grade and speed increments and in stage duration. Achievement of the traditional plateau criterion may be protocol and population specific. Sheehan et al. (20) examined the differences between test protocols in the frequency of achievement of $\dot{V}O_2$ max criteria in 10- to 12-year-old boys. These investigators found that more subjects met the plateau criterion with an intermittent running protocol (68.7%) than with a continuous one (56.2%). Other studies with children have also demonstrated higher frequencies of plateau achievement with intermittent running protocols (9, 10, 11).

The purpose of this study was to examine the effects of different testing protocols on the achievement of $\dot{V}O_2$ max criteria in adolescent long-distance runners. The frequency of achievement of these criteria was compared during three running maximal treadmill protocols (two continuous and one intermittent). Additionally, a comparison was made between plateau achievers and nonachievers on variables indicative of maximal effort.

**Methods**

**Subjects**

A group of 13 male adolescents 14–16 years of age, who participated in a specialized training program for long-distance running was recruited. These subjects attended a school with a special emphasis in the development of athletic potential and were selected because they were accustomed to strenuous exercise and its discomforts and were highly motivated to exercise to fatigue. They had been training in long-distance running for 2 hr/day, 5 days/week, 9 months/year, for an average of 2.2 years. Their average 1-mile time was $312.8 \pm 10.0$ s. Training sessions included a long continuous run of 4–5 miles, interval training, and a fast continuous run or fartlek running.
Procedures

All tests were performed in the morning in an air-conditioned laboratory at an average temperature of 23.5 °C. Subjects were instructed not to exercise vigorously the previous day and not to eat for at least 2 hr before each test. Preceding the first exercise test, testing procedures were explained, parental written consent was obtained, and height was measured with a stadiometer. Weight was measured using an electronic scale (Ancaster Co.) before each exercise test. The subjects had been previously familiarized with testing procedures and apparatus by performing an exercise test using the Bruce protocol. Each runner completed two continuous and one intermittent running exercise test protocol on a motor driven treadmill (model 1800, Marquette Instruments). Tests were conducted to volitional fatigue, at least 48 hr apart, within a 2-week period. These protocols differed in speed and grade increments as well as in stage duration. The order of the exercise tests was random. Strong verbal encouragement was provided by experienced technicians, and the tests were terminated when the subject indicated that he could not continue. Handrail support was not permitted.

*Modified Taylor (T) Protocol.* Subjects warmed up for 3 min at 7 mph and 0% grade. The inclination was increased 2.5% every 2 min until volitional fatigue. This protocol constitutes a modification of the original Taylor protocol (21), which consists of 3-min stages.

*Bruce (B) Protocol.* Subjects warmed up for 3 min at 1.7 mph and 0% grade. The inclination was then increased to 10% for the first 3-min stage. Thereafter, both the speed and inclination were increased every 3 min according to the Bruce protocol procedures (4), until volitional fatigue.

*Taylor Intermittent (TI) Protocol.* Subjects warmed up for 3 min at 7 mph and 0% grade. The inclination was then increased 2.5% every 3 min until volitional fatigue. There was an active rest period of 3 min between workloads during which the subjects walked at 2.5 mph and 0% grade (21).

Exercise Measurements

Subjects breathed through a low resistance nonrebreathing valve (Hans Rudolph 2700) supported by a headgear. Expired air was analyzed using an AMETEK metabolic cart (Applied Electrochemistry model S-3A oxygen analyzer and model CD-3A carbon dioxide analyzer), which was calibrated before each test with certified calibration gases. Minute ventilation was measured using a flow transducer (model K 520, KL Engineering Co.) attached to the nonrebreathing valve. Gas concentrations were sampled from a mixing chamber and the 15-s mean \( \dot{V}O_2 \) and carbon dioxide production (\( \dot{V}CO_2 \)) values were averaged over 60 s and used for analysis. If a subject was unable to complete the final work stage of a test, the last 60-s or 30-s \( \dot{V}O_2 \) average of that final stage was compared to the last 60-s average of the previous work stage. Respiratory exchange ratio was calculated as \( \dot{V}CO_2/\dot{V}O_2 \). HR was recorded during the last 10 s of each minute of exercise using a Marquette electrocardiographic system (MAC 12, Marquette Instruments). The criteria for \( \dot{V}O_2\text{max} \) were (a) \( R \geq 1.0 \), (b) HR \geq 95% predicted max (220 – age), and (c) increase in \( \dot{V}O_2 \leq 2.1 \text{ ml-kg}^{-1}\text{-min}^{-1} \) with an increase in workload (plateau).
**Statistical Analysis**

A chi-square test was used to compare the frequency of criteria achievement among the different protocols. A one-way analysis of variance was used to compare maximal exercise values among protocols. A two-tailed independent t test was used to compare plateau achievers and nonachievers on peak exercise variables, within each protocol. An alpha level of $p \geq .05$ was considered significant.

**Results**

The mean ± SD age, weight, and height of the subjects was 15.0 ± 0.8 years (range = 14–16 years), 52.9 ± 6.4 kg, and 164.2 ± 5.5 cm, respectively. These athletes exhibited average $\dot{V}O_2$ values of 70.6 ± 4.2 ml·kg$^{-1}$·min$^{-1}$ during maximal exercise. These values are typical of well-trained adult long-distance runners (17).

The frequency of achievement for each criterion is shown in Figure 1. All subjects attained the R criterion during the three protocols. The criterion for HR

![Figure 1](image-url)  

*Figure 1 — Percentage of adolescent long-distance runners achieving the criteria for $\dot{V}O_2$max during three different testing protocols. *Different from modified Taylor and Bruce ($p < .05$).*
was met by 85% of subjects during the T protocol, 77% during the B protocol, and 92% during the TI protocol \((p > .05)\). The frequency of plateau achievement was higher during the TI protocol \((T = 54\%, \ B = 39\%, \ \text{and} \ TI = 85\%, \ p < .05)\).

Maximal exercise variables for the three protocols are shown in Table 1. Maximal HR and ventilation \((V_e)\) were similar in all protocols \((p > .05)\). Maximal R was lower during the TI protocol \((p < .5)\). The TI protocol took twice as long to complete as the B protocol and three times as long as the T protocol \((p < .05)\). However, no differences were found between the protocols in \(\dot{VO}_2\) at volitional fatigue \((T = 70.8 \pm 4.1, \ B = 71.4 \pm 3.5, \ TI = 69.6 \pm 5.0 \ \text{ml.kg}^{-1}.\text{min}^{-1}, \ p > .05)\).

Figure 2 shows \(\dot{VO}_2\) values for plateau achievers and nonachievers during progressive exercise for the three protocols. Table 2 presents a comparison between those who achieved a plateau and those who did not, in maximal exercise variables. No differences were found in \(\dot{VO}_2\), HR, R, \(V_e\), or test duration at volitional fatigue during any of the three protocols \((p > .05)\).

The average change in \(\dot{VO}_2\) among submaximal exercise stages was 6.4 ml.kg\(^{-1}\).min\(^{-1}\) (range = 4.1–9.0) for the T protocol, 11.8 ml.kg\(^{-1}\).min\(^{-1}\) (range = 7.9–14.0) for the B protocol, and 5.2 ml.kg\(^{-1}\).min\(^{-1}\) (range = 2.9–6.8) for TI protocol. These values are higher than the average \(\dot{VO}_2\) increment of 4.2 \pm 1.1 ml.kg\(^{-1}\).min\(^{-1}\) for a 2.5% grade increment reported in the original study by Taylor et al. (21), which was used as a basis to establish the plateau criterion of 2.1 ml.kg\(^{-1}\).min\(^{-1}\).

**Discussion**

Objective criteria for \(\dot{VO}_2\)max have been established in adults to assure a true maximal effort during progressive exercise tests to volitional fatigue. Studies with adolescents have shown that while a high percentage of subjects satisfy the R and HR criteria, a \(\dot{VO}_2\) plateau is less commonly attained \((1, 2, 6, 7, 14, 15, 16, 20)\). The main findings of the present study were the following: (a) In adolescent long-distance runners, the characteristics of a protocol can determine the frequency of a plateau achievement but have no effect on the attainment of the R or HR criteria; and (b) \(\dot{VO}_2\) during running exercise to volitional fatigue was independent of the testing protocol.

For a plateau in \(\dot{VO}_2\) to be attained, the neural and muscular actions associated with force production must remain viable while anaerobic processes increase disproportionately \((8)\). Localized muscular fatigue may prevent an untrained or moderately active subject from enduring increases in power output at maximal exercise necessary to exhibit a plateau in \(\dot{VO}_2\). We selected long-distance runners who were accustomed to strenuous exercise and who exhibited \(\dot{VO}_2\)max values that are higher than those of highly trained prepubertal children and typical of well-trained adult endurance runners \((17)\), to increase the probability of observing a plateau in \(\dot{VO}_2\). However, during two of the protocols used, a significant number of subjects did not exhibit a plateau.

A variety of treadmill testing protocols, continuous and intermittent, are utilized to assess the cardiopulmonary capacity of adolescents. These protocols differ from the original protocols used to establish \(\dot{VO}_2\)max criteria in adults, in total duration, in power increments at each exercise stage, and in stage duration.
Table 1  Maximal Exercise Variables of Adolescent Long-Distance Runners

<table>
<thead>
<tr>
<th></th>
<th>Modified Taylor</th>
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<th>Bruce</th>
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<th>Taylor intermittent</th>
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<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>$\dot{V}O_2$ (ml·kg$^{-1}$·min$^{-1}$)</td>
<td>70.8</td>
<td>4.1</td>
<td>71.4</td>
<td>3.5</td>
<td>69.6</td>
<td>5.0</td>
</tr>
<tr>
<td>HR (beats·min$^{-1}$)</td>
<td>207.3</td>
<td>8.7</td>
<td>204.6</td>
<td>10.1</td>
<td>206.4</td>
<td>7.5</td>
</tr>
<tr>
<td>$R$</td>
<td>1.2</td>
<td>0.1</td>
<td>1.2</td>
<td>0.1</td>
<td>1.1</td>
<td>0.1*</td>
</tr>
<tr>
<td>$\dot{V}E$ (L·min$^{-1}$)</td>
<td>119.3</td>
<td>18.9</td>
<td>122.0</td>
<td>18.5</td>
<td>123.6</td>
<td>19.3</td>
</tr>
<tr>
<td>Duration (s)</td>
<td>620.8</td>
<td>62.9</td>
<td>904.6</td>
<td>138.5**</td>
<td>1866.9</td>
<td>215.7*</td>
</tr>
</tbody>
</table>

*Different from modified Taylor and Bruce, $p < .05$. **Different from modified Taylor, $p < .05$.

Figure 2 — Oxygen consumption during progressive exercise in adolescent long-distance runners who did (P) and did not (No P) achieve a plateau during three different testing protocols.
Table 2  Maximal Exercise Variables in Adolescent Long-Distance Runners Who Showed a Plateau and No Plateau in Oxygen Consumption

<table>
<thead>
<tr>
<th></th>
<th>Modified Taylor Plateau (n=7)</th>
<th>Modified Taylor No plateau (n=6)</th>
<th>Bruce Plateau (n=5)</th>
<th>Bruce No plateau (n=8)</th>
<th>Taylor intermittent Plateau (n=11)</th>
<th>Taylor intermittent No plateau (n=2)</th>
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<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>$\dot{V}\text{O}_2$ (ml·kg$^{-1}$·min$^{-1}$)</td>
<td>69.7</td>
<td>3.5</td>
<td>72.1</td>
<td>4.7</td>
<td>70.8</td>
<td>3.0</td>
</tr>
<tr>
<td>HR (beats·min$^{-1}$)</td>
<td>205.2</td>
<td>7.4</td>
<td>210.4</td>
<td>9.5</td>
<td>205.2</td>
<td>8.7</td>
</tr>
<tr>
<td>$R$</td>
<td>1.1</td>
<td>0.1</td>
<td>1.1</td>
<td>0.1</td>
<td>1.1</td>
<td>0.1</td>
</tr>
<tr>
<td>$\dot{V}_E$ (L·min$^{-1}$)</td>
<td>123.4</td>
<td>20.2</td>
<td>114.6</td>
<td>17.8</td>
<td>125.5</td>
<td>21.3</td>
</tr>
<tr>
<td>Test duration (s)</td>
<td>642.8</td>
<td>23.6</td>
<td>595.0</td>
<td>85.7</td>
<td>882.0</td>
<td>226.1</td>
</tr>
</tbody>
</table>
It is possible that achievement of criteria for \( \dot{V}O_2_{\text{max}} \) depends on the specific characteristics of both the protocol and the population being studied. In fact, with the two continuous protocols, we found similar rates of achievement for the HR and R criteria and a higher rate of plateau achievement than in a previous investigation of active adolescents who completed the Bruce protocol (16). However, the rates of plateau achievement of 54% and 39% for the T and B protocol, respectively, are considerably low.

Taylor et al. (21) established the plateau criterion based on responses of adult subjects to an intermittent running protocol. The investigators observed that while running at 7 mph, the mean increase in oxygen uptake per 2.5% grade increment was 4.2 ± 1.1 ml·kg\(^{-1}\)·min\(^{-1}\). Based on these data, they assumed that \( \dot{V}O_2_{\text{max}} \) had been attained when a work increase was not accompanied by an increase in \( \dot{V}O_2 \) of at least 50% of the mean increase in \( \dot{V}O_2 \) per workload increment or 2.1 ml·kg\(^{-1}\)·min\(^{-1}\). In the present study the average change in \( \dot{V}O_2 \) between submaximal exercise stages was 6.4 ml·kg\(^{-1}\)·min\(^{-1}\) and 11.8 ml·kg\(^{-1}\)·min\(^{-1}\) for the T and B protocols, respectively. Therefore, based on Taylor et al.’s (21) methodology, our criteria would be 3.2 ml·kg\(^{-1}\)·min\(^{-1}\) for the T protocol and 5.9 ml·kg\(^{-1}\)·min\(^{-1}\) for the B protocol. If we apply these criteria to our data, the frequency of plateau achievement would increase to 85% for the T protocol and 69% for the B protocol. Our findings suggest that it is not appropriate to use a criterion of ≤ 2.1 ml·kg\(^{-1}\)·min\(^{-1}\) in adolescents who exhibit different \( \dot{V}O_2 \) responses during submaximal exercise stages of continuous running protocols. Identifying a plateau based on criteria developed using group responses to the specific testing protocol may increase the rate of plateau achievement.

The intermittent protocol used in this study was similar to the protocol used by Taylor et al. (21) to establish the plateau criterion. The increase in \( \dot{V}O_2 \) per submaximal workload during the TI protocol (5.2 ml·kg\(^{-1}\)·min\(^{-1}\)) was similar to that found by Taylor et al. The high rate of plateau achievement (85%) with the intermittent protocol is in agreement with previous reports in children that have shown high rates of plateau achievement (ranging from 69–95%) during intermittent running protocols (9, 10, 11, 20). The delay in the rise in \( \dot{V}O_2 \) at high work rates during the intermittent protocol may have increased the likelihood of observing a plateau.

A very long intermittent test in adolescent subjects may not be warranted for several reasons. Achieving a plateau had no effect on \( \dot{V}O_2 \) during maximal exercise, a finding that has been previously observed in children (19). Additionally, it has been shown that the optimal test duration when measuring aerobic power ranges from 8 to 17 min (5). An adolescent performing a prolonged intermittent test may become bored and lose motivation, resulting in a failure to reach maximal effort (18). Our subjects expressed a preference for the T protocol, which was the shortest of the three protocols used in the present study. They felt uncomfortable and complained about the testing apparatus during the TI protocol. Our subjects were accustomed to the discomforts of exercise, were highly motivated, and capable of a maximal effort. This may not be the case for other adolescents.

Noakes (13) postulates that even when the plateau phenomenon has been identified in a subject, biochemical evidence of tissue hypoxia will also be needed to prove that an oxygen limitation is present. The fact that \( \dot{V}O_2_{\text{max}} \) was similar in those who achieved a plateau and those who did not, irrespective of the
protocol, indicates that oxygen delivery does not always limit exercise capacity. Similar responses for other indicators of maximal effort support this conclusion. For those who reached volitional fatigue and did not exhibit a plateau in VO₂, additional factors other than oxygen availability, such as an inability to activate the appropriate muscles at peak exercise or an impairment in the excitation–contraction process of the active muscles may be limiting exercise capacity (8). Furthermore, Myers et al. (12) have suggested that the occurrence of a plateau may be random. They observed that a plateau in VO₂, defined as the slope of a VO₂ sample at peak exercise that did not differ from zero, was not a consistent finding within subjects and between days.

In summary, this study indicates that the characteristics of a protocol can determine the frequency of a plateau achievement but have no effect on the attainment of the R and HR criteria during progressive exercise to volitional fatigue. When testing adolescents with protocols that differ from the ones used to establish the plateau criterion, it may be more appropriate to identify a plateau based on criteria developed using group responses to the specific protocol. The fact that VO₂ at volitional fatigue was independent of the testing protocol and the complexity associated with tests of prolonged duration suggest that intermittent running protocols may not be the most appropriate tests for assessing the cardiorespiratory capacity of adolescents.

References


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