Running Speed at Predicted Maximal Heart Rate as an Assessment of Maximal Aerobic Capacity in Trained Teenaged Runners

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Purpose: The purpose of this study was to examine whether the running speed (vHRmax.ped) corresponding to a HRmax predicted by the formula [220-age (yrs)], is a useful physiologic index of endurance among trained young runners in a specified age group (12-20 yrs). Correlations were analyzed between vHRmax.ped and \( V_{\text{o}_2}\max, vV_{\text{o}_2}\max \) (running speed corresponding to \( V_{\text{o}_2}\max \), vLT (running speed at a blood lactate level of 4 mmol·L\(^{-1}\)), vHRmax.meas (running speed at the measured HRmax), and competitive 1500 and 3000-m performance times in 43 endurance-trained, teenaged runners (25 males, 18 females).

Methods: Physiological variables (\( V_{\text{o}_2}, HR, \) and La) were measured during progressive sub-maximal and maximal treadmill running. Running speeds corresponding to \( V_{\text{o}_2}\max, HRmax.meas, \) and HRmax.ped were estimated from regressions relating each individual's running speed to \( V_{\text{o}_2} \) and HR.

Results: With a few exceptions, gender-specific correlation coefficients were significant between \( V_{\text{o}_2}\max, vV_{\text{o}_2}\max, vLT, vHRmax.meas, \) and vHRmax.ped, with values ranging from 0.41 to 0.93 (\( p<0.05 \)). vHRmax.ped was a significant predictor of running performance for both 1500 and 3000-m events (\( r=-0.62 \) and \( -0.52 \) in males, and \( -0.66 \) and \( -0.80 \) in females, respectively).

Conclusion: The results suggested that vHRmax.ped is a useful predictor of endurance running performance in trained teenaged runners. This fact also suggested the possibility of developing an index of endurance running performance in untrained teenagers.

Keywords: maximal oxygen intake, maximal heart rate, running speed, running performance

Introduction

The performance of endurance athletes depends upon the fractional utilization of \( V_{\text{o}_2}\max \) (%\( V_{\text{o}_2}\max \) (di Prampero et al., 1986; Morgan et al., 1989), and, thus, the individual's \( V_{\text{o}_2}\max \) and running economy (RE, \( V_{\text{o}_2} \) at a specified, sub-maximal running speed) (Conley and Krahenbuhl, 1986; Lacour et al., 1991; Yamaji, 1997). Daniels (1985) and di Prampero et al. (1986) found that, in adults, the velocity at the maximal oxygen intake (v\( V_{\text{o}_2}\max \)), depending on \( V_{\text{o}_2}\max \) and RE, was a useful marker of running-related endurance. \( V_{\text{o}_2}\max \) and RE both bear a close relationship to the average running velocity over events ranging from a 1500-m race to a full-length marathon (Bethon et al., 1997; Hill and Rowell, 1996; Lacour et al., 1991). Though the directly measured \( V_{\text{o}_2}\max \) and v\( V_{\text{o}_2}\max \) are the most precise physiologic markers of aerobic capacity in runners, such measurements are not always feasible or convenient. Determinations of \( V_{\text{o}_2}\max \) and v\( V_{\text{o}_2}\max \) require bulky and expensive equipment, and maximal running on a level treadmill
carries appreciable risks, regardless of whether subjects are untrained or experienced runners. Therefore, a useful index that takes the place of \( \text{V\cdot} \text{O}_2\text{max} \) and \( v\text{V\cdot} \text{O}_2\text{max} \) is required.

The HR is easily measurable and a more convenient marker of exercise intensity than \( \text{V\cdot} \text{O}_2 \). Further, the HR of most subjects appears to increase linearly with running speed until it levels off at the maximal aerobic output. The steady-state HR for a particular running speed has been used to evaluate both aerobic capacity and RE (Rowland et al., 1993; Wahlund, 1948). As HRmax can also be predicted by the formula [220-age (yrs)], we thus anticipated that \( v\text{HR\cdot} \text{max}\text{.pred} \) would be a useful predictor of endurance running performance for a wide range of ages. To verify this hypothesis, we compared \( v\text{HR\cdot} \text{max}\text{.pred} \) and related physiological indices with the performance of endurance-trained young runners, using 1500 and 3000-m performance times. Furthermore, if this hypothesis can be supported, there is a strong possibility that \( v\text{HR\cdot} \text{max}\text{.pred} \) can be applied as an index of endurance running performance, not only in untrained young persons, but also in untrained persons over a wide age range.

### Materials and Methods

#### Subjects

Teenaged runners (25 males, 12-18 yrs; 18 females, 14-20 yrs) were recruited from junior- and high-school as well as university running clubs (Table 1). All subjects had been training regularly (4-7 days a week, 1-2 hours per session) for 2-6 years. Another 7 males and 7 females from high-school cross-country ski clubs participated in reliability tests; they also had been running regularly during their off-season (from March to November), and several had attended long-distance track and road races during the summer months. All subjects were familiar with running on the type of treadmill used in this study.

Running test sessions were done between March and November. The purpose of the study and associated risks were explained to the subjects (and also to their parents in the case of junior high school students). All agreed to participate in the study, and signed consent forms in accordance with a protocol approved by the University Committee on Human Experimentation. Data were collected in a laboratory at a temperature of \( 20\pm1 \)°C, and a relative humidity of 50\%±5%. Each subject was tested at a consistent time, on the same weekday.

#### Treadmill running test procedures

After a 10-min warm-up (150-m \( \text{min}^{-1} \) for males and 130-m \( \text{min}^{-1} \) for females), physiological responses were tested using a treadmill protocol with a zero slope, and step-wise increases of speed. Observations began at a treadmill speed chosen to elicit a HR of 110-130 beats \( \text{min}^{-1} \), and the speed was increased by 10-m \( \text{min}^{-1} \) every minute to a maximum of 270-350 m \( \text{min}^{-1} \) (K.K. Nishikawa treadmill, Kyoto, Japan). Subjects wore a safety harness around their waists and chests while they were on the treadmill. The HR was measured during the last 10 s of each treadmill stage. After a 10-min rest interval, the definitive test began at a running speed determined by the fitness of the individual (180-210-m \( \text{min}^{-1} \) for males and 150-180-m \( \text{min}^{-1} \) for females), and the speed was increased by 30-m \( \text{min}^{-1} \) every 3 min, with 1-min rest intervals, until subjects were exhausted or the test ended.

#### Physiological observations

Disposable electrodes were attached to the chest to measure HR by ECG telemetry (Bioview 1000; NEC & Sanei Corporation, Tokyo, Japan). Expired gas was fed continuously via a face mask and clear 35-mm-bore

#### Table 1  Anthropometric characteristics, physiologic variables, and competitive running performance times in males and females.

<table>
<thead>
<tr>
<th></th>
<th>Age (yrs)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Fat (%)</th>
<th>( \text{VO}_2\text{max} ) (l ( \text{min}^{-1} ))</th>
<th>( \text{V\cdot} \text{O}_2\text{max} ) (ml ( \text{kg}^{-1} \text{min}^{-1} ))</th>
<th>( v\text{VO}_2\text{max} ) (m ( \text{min}^{-1} ))</th>
<th>( v\text{HR\cdot} \text{max}\text{.pred} ) (m ( \text{min}^{-1} ))</th>
<th>vLT (m ( \text{min}^{-1} ))</th>
<th>1500-m time (s)</th>
<th>3000-m time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males (n=25)</td>
<td>14.8±1.1</td>
<td>164.6±6.7</td>
<td>49.9±6.6</td>
<td>10.4±0.8</td>
<td>3.22±0.48</td>
<td>64.5±4.3</td>
<td>310.5±21.0</td>
<td>308.4±21.1</td>
<td>279.3±17.4</td>
<td>269.4±19.5</td>
<td>571.4±26.8</td>
</tr>
<tr>
<td>Females (n=18)</td>
<td>14.7±1.7</td>
<td>155.1±3.8</td>
<td>45.3±4.1</td>
<td>15.4±1.9</td>
<td>2.54±0.40</td>
<td>56.0±6.6</td>
<td>275.8±27.7</td>
<td>273.2±27.3</td>
<td>290.8±29.2</td>
<td>316.4±19.1</td>
<td>668.0±34.5*</td>
</tr>
</tbody>
</table>

1500 and 3000-m times: the best running performance times for 1500 and 3000-m during the track-and-field season when this was performed.

* \( n=10 \).

* \( p<0.05 \): significant difference between \( v\text{HR\cdot} \text{max}\text{.pred} \) and \( v\text{VO}_2\text{max} \), \( v\text{HR\cdot} \text{max}\text{.pred} \).
tubing to a mixing chamber with baffles and then to a conventional metabolic cart (Innovation Automatic Metabolic Analysis Machine, AMIS 1000SM, Odense, Denmark); O₂ and CO₂ concentrations were monitored on a breath-by-breath basis, with V̇O₂ and pulmonary ventilation (V̇E) calculated for each 30-s segment of exercise. The highest observed HR (HRmax) was also noted. Lactate concentrations (La) were measured from finger-tip blood samples, using a Lactate Pro analyzer (Arkray KK, Kyoto, Japan); samples were collected immediately after completing each running segment. Lactate readings were also obtained at exhaustion, and 40-50 s later, the highest one of these last two readings was regarded as the peak La. The running speed leading to a blood lactate concentration of 4 mmol·L⁻¹ was determined by plotting the relation between each running speed and La. We adopted this running speed as the vLT.

Assessing V̇O₂max

V̇O₂ which met at least three of the following four criteria was regarded as V̇O₂max: ① V̇O₂ reached a plateau (<2.0 ml·kg⁻¹·min⁻¹), ② measured HRmax + 10 beats·min⁻¹ > HRmax predicted by the formula [220-age(yrs)], ③ RQ > 1.0, ④ peak LA > 10 mmol·L⁻¹.

Estimation of vV̇O₂max, vHRmax, and vLT

vV̇O₂max was estimated from a plot of each individual’s V̇O₂ against the running speed (Figure 1). vHRmax.meas and vHRmax.pred were estimated from a plot of each individual’s HR against the running speed, using the observed HRmax and the value predicted by the equation [220-age (yrs)], respectively (Figure 2). The running speed at a blood lactate concentration of 4 mmol·L⁻¹ was adopted as the vLT (running speed at the lactate threshold, LT).

Reliability tests

The reliability of V̇O₂max, vV̇O₂max, vLT, and vHRmax.pred was determined by following a similar protocol, which was separated by about a one-month period, involving 7 male and 7 female cross-country skiers.

Statistical analyses

Statistical analyses were performed using a SPSS statistical package for personal computers (SPSS, 1990). Calculations included Pearson’s correlation coefficients and repeated-measures ANOVA to assess
differences between each individual’s scores in the first and second series of tests. Significant differences between velocity variables were examined using one-way ANOVA and Scheffe’s post-hoc comparisons. A probability value of \( p < 0.05 \) was considered significant for all analyses. All values were expressed as the mean±SE.

**Results**

The physical characteristics and physiological variables are much as might be anticipated in well-trained teenaged endurance runners (Table 1). Correlations between the physiological variables and endurance running times (1500 and 3000-m) are summarized in Tables 2 and 3. With few exceptions, correlations between the gender-specific 1500 and 3000-m times and \( V_\text{O}_\text{2max} \), \( vV_\text{O}_\text{2max} \), \( vLT \), \( vHR\text{max.meas} \), and \( vHR\text{max.pred} \) were almost all significant, with absolute values ranging from \( r = 0.41 \) to 0.93 (\( p < 0.05 \)), with the exceptions being \( vLT \) vs. \( vHR\text{max.pred} \) for males and \( vHR\text{max.meas} \) vs. 3000-m times, and \( vLT \) vs. 3000-m times for females. Respective relationships between \( vHR\text{max.pred} \) and running times were significant for both males and females (1500-m, \( r = -0.62 \) and \( -0.66 \), Figure 3; 3000-m, \( r = -0.52 \) and \( -0.80 \), Figure 4).

The reliability tests identified a close relationship between mean values for the first and second tests, with acceptable test-retest coefficients of variation; respective data for \( V_\text{O}_\text{2max} \), \( vHR\text{max.meas} \), \( vHR\text{max.pred} \), and \( vLT \) in the 14 subjects were 55.4±1.8 and 56.7±1.7 ml·kg\(^{-1}\)·min\(^{-1}\) (CV: 12.3%, 11.3%), 208.9±10.1 and 285.8±8.2 m·min\(^{-1}\) (CV: 12.0%, 9.5%), 297.3±9.9 and 295.2±8.7 m·min\(^{-1}\) (CV: 12.4%, 11.0%), and 237.8±10.4 and 244.8±10.2 m·min\(^{-1}\) (CV: 14.6%, 13.8%).

**Discussion**

It is well-known that the HR at a given velocity and workload is a useful predictor of endurance running performance, like Conconi’s test and PWC\(_{170}\) (Sjöstrand, 1947; Wahlund, 1948; Conconi et al., 1982; 1996). This does not, however, apply over a wide range of ages, because the HR response during maximal and sub-maximal exercise is age-dependent. So, in this study we examined whether \( vHR\text{max.pred} \), the running

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**Table 2** Correlation matrix for physiologic variables and competitive running performance times in teenaged male runners.

<table>
<thead>
<tr>
<th>Number</th>
<th>Variables</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( V\text{O}_\text{2max} ) (l·min(^{-1}))</td>
<td>—</td>
<td>.423*</td>
<td>.696**</td>
<td>.613**</td>
<td>.470*</td>
<td>.680**</td>
<td>— .448*</td>
<td>— .453*</td>
</tr>
<tr>
<td>2</td>
<td>( V\text{O}_\text{2max} ) (ml·kg(^{-1})·min(^{-1}))</td>
<td>—</td>
<td>.724**</td>
<td>.547**</td>
<td>.501*</td>
<td>.408*</td>
<td>.586**</td>
<td>— .596**</td>
<td>— .629**</td>
</tr>
<tr>
<td>3</td>
<td>( vV\text{O}_\text{2max} ) (m·min(^{-1}))</td>
<td>—</td>
<td>.701**</td>
<td>.595**</td>
<td>.722**</td>
<td>— .582**</td>
<td>— .618**</td>
<td>—</td>
<td>— .629**</td>
</tr>
<tr>
<td>4</td>
<td>( vHR\text{max.meas} ) (m·min(^{-1}))</td>
<td>—</td>
<td>.835**</td>
<td>.480*</td>
<td>.749**</td>
<td>— .749**</td>
<td>— .687**</td>
<td>—</td>
<td>— .687**</td>
</tr>
<tr>
<td>5</td>
<td>( vHR\text{max.pred} ) (m·min(^{-1}))</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>6</td>
<td>( vLT ) (m·min(^{-1}))</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>7</td>
<td>1500-m times (s)</td>
<td>.933**</td>
<td>.933**</td>
<td>.933**</td>
<td>.933**</td>
<td>.933**</td>
<td>.933**</td>
<td>.933**</td>
<td>.933**</td>
</tr>
<tr>
<td>8</td>
<td>3000-m times (s)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

* \( p < 0.05 \) ** \( p < 0.01 \).

**Table 3** Correlation matrix for physiologic variables and competitive running performance times in teenaged female runners and a young female runner.

<table>
<thead>
<tr>
<th>Number</th>
<th>Variables</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( V\text{O}_\text{2max} ) (l·min(^{-1}))</td>
<td>—</td>
<td>.816**</td>
<td>.721**</td>
<td>.655**</td>
<td>.601**</td>
<td>.701**</td>
<td>— .765**</td>
<td>— .756**</td>
</tr>
<tr>
<td>2</td>
<td>( V\text{O}_\text{2max} ) (ml·kg(^{-1})·min(^{-1}))</td>
<td>—</td>
<td>.815**</td>
<td>.735**</td>
<td>.470**</td>
<td>.821**</td>
<td>— .795**</td>
<td>— .731*</td>
<td>—</td>
</tr>
<tr>
<td>3</td>
<td>( vV\text{O}_\text{2max} ) (m·min(^{-1}))</td>
<td>—</td>
<td>.909**</td>
<td>.768**</td>
<td>.908**</td>
<td>.808**</td>
<td>— .808**</td>
<td>— .666**</td>
<td>—</td>
</tr>
<tr>
<td>4</td>
<td>( vHR\text{max.meas} ) (m·min(^{-1}))</td>
<td>—</td>
<td>—</td>
<td>.773**</td>
<td>.906**</td>
<td>.734**</td>
<td>— .734**</td>
<td>— .531</td>
<td>—</td>
</tr>
<tr>
<td>5</td>
<td>( vHR\text{max.pred} ) (m·min(^{-1}))</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>6</td>
<td>( vLT ) (m·min(^{-1}))</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>7</td>
<td>1500-m times (s)</td>
<td>.705*</td>
<td>.705*</td>
<td>.705*</td>
<td>.705*</td>
<td>.705*</td>
<td>.705*</td>
<td>.705*</td>
<td>.705*</td>
</tr>
<tr>
<td>8</td>
<td>3000-m times (s)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

* \( p < 0.05 \) ** \( p < 0.01 \).
speed at the predicted HRmax with consideration of age, is a useful predictor of endurance running performance.

The relationship between the running speed and \( \dot{V}O_2 \) and/or HR was linear in all of our subjects until the leveling-off phenomenon appeared. Daniels (1985) previously noted that, in adult runners, the interplay of \( \dot{V}O_2 \)max, \%\( \dot{V}O_2 \)max, and running economy culminated in the running velocity at \( \dot{V}O_2 \)max (\( v\dot{V}O_2 \)max). Many other investigators (Lacour et al., 1991; Bethon et al., 1997; Almarwaey et al., 2003) have confirmed the strength of relationships between \( v\dot{V}O_2 \)max (or \( v\dot{V}O_2 \)peak) and the running speeds of middle- and long-distance runners. The determination of \( v\dot{V}O_2 \)max, however, requires bulky and expensive equipment. The HR (like \( \dot{V}O_2 \)) also increases linearly with increments in running speed (Conconi et al., 1982; Ribeiro et al., 1985; Conconi et al., 1996), suggesting that the HR at a specified running speed could provide a useful index of endurance capacity.

However, \( vHR_{\text{max, pred}} \), unlike PWC\(_{170} \) (Sjöstrand, 1947; Wahlund, 1948), would be a useful predictor of endurance performance for specified age groups, because a HRmax predicted by the formula [220-age (yrs)] takes account of the age. So, our data suggest that \( vHR_{\text{max, pred}} \) can be used instead of \( v\dot{V}O_2 \)max as an effective predictor of distance running performance in young runners.

Measurement problems

The classical studies of Sjöstrand (1947) and Wahlund (1948) recommended measuring PWC\(_{170} \) by arranging three test sessions with respective exercise HRs of 115-130 beats·min\(^{-1}\), 130-145 beats·min\(^{-1}\), and 160-180 beats·min\(^{-1}\). When estimating the HR threshold (HRT), based on the appearance of a HR break-point (Vd) (the point of transition from the linear to the curvilinear phase between running speed and HR), Conconi and coworkers (1982; 1996) recommended limiting HR increases per test stage to eight beats·min\(^{-1}\) or less. Brooke and Hamley (1972) and Pokan et al. (1993) further noted that the relationship between the HR and work rate was curved at HRs below 100 beats·min\(^{-1}\). We thus set the running speed of the first running test session to yield a HR between 110 and 130 beats·min\(^{-1}\). The running speed was then increased by 30·m·min\(^{-1}\) every three minutes; 6/25 male and 3/18 female runners showed a linear HR/work rate relationship for only the first three sessions, but the relationship was linear in four or more sessions for all of the remaining subjects. However, all runners ultimately showed a clear HR break-point (Vd).

The reliability tests demonstrated the stability of values for \( \dot{V}O_2 \)max, \( v\dot{V}O_2 \)max, \( vLT \), \( vHR_{\text{max, meas}} \), and \( vHR_{\text{max, pred}} \). Furthermore, \( vHR_{\text{max, meas}} \) and \( vHR_{\text{max, pred}} \) were closely correlated with various physiological indices such as \( \dot{V}O_2 \)max, \( v\dot{V}O_2 \)max, and \( vLT \) (\( p<0.05 \)). Therefore, we may conclude that the measurements adopted in this study were reliable.

There was a significant difference between \( vHR_{\text{max, meas}} \) and \( vHR_{\text{max, pred}} \); the choice between
measured and predicted HRmax thus becomes an important issue. As in some previous studies of adult athletes, our data also showed that the predicted HRmax ($205.2 \pm 0.2$, $205.3 \pm 1.7$) was significantly higher than the directly measured HRmax ($197.6 \pm 1.1$, $198.7 \pm 9.6$). Furthermore, strong statistical evidence (Gellish et al., 2007) showed that a HRmax predicted by the formula [220-age (yrs)] was higher than the measured HRmax for men and women under the age of 40 yrs, and it underestimated the true HRmax for those older than 40. The reported linear equation [206.9 $-$ (0.67 $\times$ age)], which was derived from a mean follow-up of 9 yrs (range: 5-17 yrs), provided a more accurate HRmax estimate (Jackson, 2007). We calculated HRmax using this linear equation. HRmax values for males and females were estimated as 197.0 and 196.5 beats $\cdot$ min$^{-1}$, respectively. These estimated HRmax values were near the directly measured HRmax of males and females in this study. From the viewpoint of testing, there is a marked difference between vHRmax, and vLT, as well as 1500 and 3000-m times ($p < 0.05$) in females. There were no significant differences in the average $V_{\text{o}2}$max between the two studies (64.5 $\pm$ 0.9 vs. 63.1 $\pm$ 6.1 ml $\cdot$ kg$^{-1}$ $\cdot$ min$^{-1}$). The quality of our data is further substantiated by the strength of relationships between $V_{\text{o}2}$max, $vV_{\text{o}2}$max, vHRmax, and vLT. Also, vHRmax.meas and vHRmax.pred were significantly related to 1500 and 3000-m competitive times, and (with the few exceptions noted above) the various physiological indices of endurance running performance. In addition, as there was a significant relationship between vHRmax.pred and relative $V_{\text{o}2}$max, we could estimate the relative $V_{\text{o}2}$max from the vHRmax.pred calculated.

We adopted a blood lactate concentration of 4 mmol $\cdot$ L$^{-1}$ when estimating vLT. In this study, no significant relationship was observed between vHRmax.meas and vLT in male runners. Almarwaey et al. (2003) argued for a fixed (La) of 2.5 mmol $\cdot$ L$^{-1}$ when a single blood lactate value was used to assess distance running performance in trained adolescents. Their proposal has received some previous support (Williams and Armstrong, 1991; Jackson, 2007), although other investigators (Eriksson and Koch, 1973) would argue for the figure of 4 mmol $\cdot$ L$^{-1}$ that we adopted (LT). In this study, there was no significant relationship between peak La, lactic acid measured at the point of exhaustion, and age (yrs) for both males and females. Further studies should, however, examine the influence of differences in LT on the strength of relationships with running speed.

The reason why vHRmax.meas was not related to 3000-m times in females needs further study. However, plainly, maximal exertion is needed to obtain an accurate value for vHRmax.meas, and, for this reason, vHRmax.pred may be a better choice, particularly when assessing less competitive adolescents as well as adults.

In conclusion, since the HR is an easily measurable and more convenient marker of exercise intensity than $V_{\text{o}2}$, and 2 HRmax can be predicted by a linear equation. However, to more accurately estimate the HRmax, we have to further investigate which linear equation is more convenient for both males and females. Further studies should, however, examine the influence of differences in LT on the strength of relationships with running speed.

Ultimately, 1 the HR is an easily measurable and more convenient marker of exercise intensity than $V_{\text{o}2}$, and 2 HRmax can be predicted by a linear equation. Therefore, vHRmax.pred seems to be a more useful and convenient index of endurance running performance than v$V_{\text{o}2}$max in young runners, and it will be interesting to explore how far it can be applied to subjects in other age ranges. vHRmax.pred estimated from a progressive sub-maximal treadmill run has the potential to become a practical index of peak aerobic power.

**Relationships between $vHRmax$ and $vV_{\text{o}2}$max, $vV_{\text{o}2}$max, and vLT**

To date, $V_{\text{o}2}$max, v$V_{\text{o}2}$max, and vLT have all been used as physiological indices of endurance running performance; (Morgan et al., 1989; Lacour et al., 1991). In this study, running speed on a treadmill was intermittently increased until each subject became exhausted or the test ended. All our $V_{\text{o}2}$max values met at least two of three criteria: a respiratory gas exchange ratio (R) > 1.0, a blood lactate $> 10$ mmol $\cdot$ L$^{-1}$, and HRmax within 10% of the value predicted from the equation [220-age (yrs)]. We have further confidence in our $V_{\text{o}2}$max values because the nine subjects participated in other studies (Yamaji et al., 2000a; 2000b), where the treadmill speed was increased by 10-m $\cdot$ min$^{-1}$, starting at 180-m $\cdot$ min$^{-1}$ in males and 150-m $\cdot$ min$^{-1}$ in females. There were no significant differences in the average $V_{\text{o}2}$max between the two studies (64.5 $\pm$ 0.9 vs. 63.1 $\pm$ 6.1 ml $\cdot$ kg$^{-1}$ $\cdot$ min$^{-1}$).
young runners. Results suggested that \( vHRmax_{\text{pred}} \) offered a useful and simple index to assess endurance performance not only in young runners, but also in young non-athletes. However, further research is necessary to assess whether this is also true of the general public, and whether those who do not have access to a laboratory treadmill can use progressive field testing on a 400-m running track to estimate the relative \( \dot{V}O_{2\text{max}} \) from the formula \( vHRmax_{\text{pred}} \).

References


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