PREDICTION OF MAXIMUM OXYGEN UPTAKE BY USING THE HEART RATE RATIO METHOD IN INDIAN UNIVERSITY STUDENTS

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ABSTRACT
Sedentary male (n=94) and female (n=111) university students were randomly sampled to enumerate the prediction methods for estimating maximum oxygen uptake (VO\textsubscript{2max}) by the heart rate ratio method (HR\textsubscript{peak} · HR\textsubscript{rest}\textsuperscript{-1} or HR\textsubscript{max} · HR\textsubscript{rest}\textsuperscript{-1}). VO\textsubscript{2max} was directly measured by incremental bicycle exercise whereas equations of Uth et al. (2004) were used for indirect prediction of VO\textsubscript{2max}. The difference between directly measured VO\textsubscript{2max} (males: 38.95±3.81 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}; females: 35.90±3.46 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}) and predicted VO\textsubscript{2max} or P VO\textsubscript{2max} (males: 38.87±1.15 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}; females: 36.24±1.94 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}) from HR\textsubscript{peak}·HR\textsubscript{rest}\textsuperscript{-1} or estimated VO\textsubscript{2max} or E VO\textsubscript{2max} (males: 37.72±2.55 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}; females: 37.20±1.50 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}) from HR\textsubscript{max}·HR\textsubscript{rest}\textsuperscript{-1} was statistically insignificant. Correlation between VO\textsubscript{2max} with P VO\textsubscript{2max} (r=0.87 in males and r=0.58 in females) and E VO\textsubscript{2max} (r=0.83 in males and r=0.79 in females) was significant (p<0.001). Regression analysis revealed standard errors of estimate of VO\textsubscript{2max} when predicted from HR\textsubscript{peak}·HR\textsubscript{rest}\textsuperscript{-1} and HR\textsubscript{max}·HR\textsubscript{rest}\textsuperscript{-1} were 1.87 ml·kg\textsuperscript{-1}·min\textsuperscript{-1} and 2.14 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}, respectively, in males and 2.09 ml·kg\textsuperscript{-1}·min\textsuperscript{-1} and 2.83 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}, respectively, in females. The results by applying these norms in the confirmatory group were in good agreement with insignificant difference of VO\textsubscript{2max} (males: 38.84±3.83 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}; females: 34.23±3.70 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}) from P VO\textsubscript{2max} (males: 38.99±3.68 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}; females: 34.47±3.55 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}) or from EVO\textsubscript{2max} (males: 38.39±3.66 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}; females: 33.87±3.52 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}). Based on the present observation, the heart rate ratio method is recommended for predicting VO\textsubscript{2max} in Indian university students.

Key words: VO\textsubscript{2max} prediction; HR\textsubscript{peak}, HR\textsubscript{rest}, HR\textsubscript{max}; sedentary students.

INTRODUCTION

Maximum oxygen uptake or VO\textsubscript{2max} is the best determinant of cardiorespiratory fitness that warrants direct estimation for obtaining the most accurate and reproducible value of the parameter with a coefficient of variation of about 2–4% (Howley et al., 1995). Direct estimation of VO\textsubscript{2max} not only requires access to expensive laboratory equipment and skilled personnel but also involves complicated, exhaustive, hazardous and a time-consuming experimental protocol (Chatterjee et al., 2005; Chatterjee et al., 2004). Consequently, alternative indirect prediction methods of VO\textsubscript{2max} have been developed in various populations (Chatterjee et al., 2005; Chatterjee et al., 2004; Kline et al., 1987; Fox, 1973; Cooper, 1968; Åstrand and Ryhming, 1954).

Negative relationship is speculated between VO\textsubscript{2max} and resting heart rate (HR\textsubscript{rest}) since training improves VO\textsubscript{2max} with a decline in HR\textsubscript{rest} while detraining leads to contradictory changes in VO\textsubscript{2max} and HR\textsubscript{rest}.
Aging is associated with decrements in VO_{2max} and maximum heart rate or HR_{max} (Tanaka et al., 2001), which in turn depicts a positive relationship between VO_{2max} and HR_{max}. Uth et al. (2004) combined the influences of training and aging on VO_{2max} and HR and established a positive relationship between VO_{2max} and the ratio between HR_{max} and HR_{rest} (HR_{max}/HR_{rest}^{-1}). They also suggested that mass specific VO_{2max} (ml·kg^{-1}·min^{-1}) may be estimated by multiplying HR_{max}/HR_{rest}^{-1} by a proportionality factor of about 15.0.

The present study was therefore aimed to examine whether this theoretical proportionality factor could be practically confirmed by experimental data in healthy sedentary Indian university students.

**METHODS**

**Subjects**

Healthy sedentary university students (94 males and 111 females) of the same socio-economic background having the mean age, body height and body mass of 22.6±1.6 years and 21.6±1.5 years, 167.4±4.0 cm and 163.5±3.3 cm and 57.9±4.0 kg and 56.5±4.1 kg, in male and female groups, respectively, were selected for the study by simple random sampling from the students of the University of Calcutta, West Bengal, India. They were randomly assigned to either of two groups. One group (named as study group, 54 males and 61 females) validated the proportionality factor between mass-specific VO_{2max} and HR_{peak}/HR_{rest}^{-1} or HR_{max}/HR_{rest}^{-1}. Data of the study group were also used to compute a regression norm to predict VO_{2max} by using the HR_{max}/HR_{rest}^{-1} method or HR_{peak}/HR_{rest}^{-1} method. The other group (named as confirmatory group, 40 males and 50 females) was used to establish the limit of agreement between directly measured VO_{2max} and predicted or estimated VO_{2max} that was calculated from the computed regression norm in the study population.

The entire experimental protocol was well explained to all the participants and written informed consent was also taken from them. They took light breakfast 2-3 hours before the test and refrained from any energetic physical activity for that period. The participants had no history of any major disease and received no physical conditioning programme except some recreational sports. The study was approved by the Human Ethical Committee of the department.

The entire experiment was performed at a room temperature varying from 26-29˚C and at a relative humidity ranging between 63 to 69%.

**Experimental protocol**

Resting heart rate was measured over a five-minute period in the morning (supine, while in the bed) on the day after the test (Uth et al., 2004). HR_{max} was predicted from the formula of Tanaka et al. (2001): HR_{max} = 208 – 0.7 × Age in years.

Each subject came to the laboratory for two days. On the first day they were familiarised with the experimental protocol. The evaluation of VO_{2max} by the direct method was conducted on the second visit. The subjects were asked to take rest at least for half an hour prior to the exercise, so that pulmonary ventilation and pulse rate could come down to a steady state (Chatterjee et al., 2005; Chatterjee et al., 2004).

**Direct measurement of maximum oxygen uptake capacity or VO_{2max} [Chatterjee et al., 2004]**

Subjects first performed a warm up exercise at 50 W intensity for a duration of 5 minute in the Muller’s magnetic brake bicycle ergometer (Model of the Max-Plank Institute of Ergology, Germany). Immediately after performing the submaximal exercise, the intensity was increased to the first incremental intensity of 100 W and 80 W in males and females, respectively, and thereafter the intensity was increased by 20 W every 3 minutes until the subject stopped due to exhaustion. The oxygen uptake was considered the maximum when the subject reached (ACSM 2006):

i) a heart beat within 10 beats·min^{-1} of the age-predicted maximum heart rate

ii) a respiratory exchange ratio is over 1.15
levelling off, i.e., when no further increase in oxygen uptake took place despite further increase in intensity, or the increase in oxygen uptake was less than 100 mL·min⁻¹ in response to the next higher intensity for repeated tests followed at an interval of 4 days (Chatterjee et al., 2004; Chatterjee et al., 2005).

Collin’s Triple “J Type” low resistance high velocity plastic valve was used for the collection of expired gas by open circuit method (Chatterjee et al., 2005; Chatterjee et al., 2004). The valve was connected with the Douglas Bag (150 L) and the expired gas was collected at the last minute of the final intensity of exercise. Gas was also collected at the second minute of the exhausting (final) work load if signs of severe exhaustion supervened. No gas collection was made in the first minute of the work load. The volume of expired gas was measured in a wet gasometer (Toshniwal, Germany, CAT. No. CG05.10) and the aliquots of gas samples were analyzed in a Scholander micro-gas analysis apparatus following the standard procedure (Scholander, 1947). The peak heart rate was recorded manually from the time taken for ten carotid pulsations immediately following the cessation of exhaustive exercise (Chatterjee et al., 2005; Chatterjee et al., 2004). VO₂₅₀₂max values were corrected to standard temperature pressure dry (STPD).

Calculation of predicted VO₂max (PVO₂max) and estimated VO₂max (EVO₂max)

The predicted VO₂max or PVO₂max and estimated VO₂max or EVO₂max were calculated by using the following formulae (Uth et al., 2004):

\[
\text{PVO}_2\text{max} (\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}) = 15.0 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1} \times \text{HR}_{\text{max}} \cdot \text{HR}_{\text{rest}}^{-1}
\]

\[
\text{EVO}_2\text{max} (\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}) = 15.0 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1} \times \text{HR}_{\text{peak}} \cdot \text{HR}_{\text{rest}}^{-1}
\]

Statistical analysis

Paired t-test, correlation and linear regression statistics were adopted for statistical analysis of the data. The Bland and Altman analysis for the limit of agreement analysis was used to test the applicability of an indirect test when it was validated in terms of the direct method (Bland and Altman, 1986). Since this research dealt with the indirect prediction of VO₂max in comparison with the direct method, the Bland and Altman method was also employed in the study. The level of significance was set at p<0.05.

RESULTS

The resting heart rate (HRrest), peak heart rate (HRpeak) and calculated maximum heart rate (HRmax) of the study group were 74.2±2.5 beats·min⁻¹, 186.3±7.1 beats·min⁻¹ and 192.2±1.1 beats·min⁻¹, respectively, in the males and 77.6±3.3 beats·min⁻¹, 187.2±4.4 beats·min⁻¹ and 192.2±1.1 beats·min⁻¹, respectively, in the females. The experimentally determined proportionality factor between VO₂max and HRpeak·HRrest⁻¹ was 15.47±0.80 mL·kg⁻¹·min⁻¹ in the males and 14.90±0.96 mL·kg⁻¹·min⁻¹ in the females. These values are close to the theoretical value of under 15 mL·kg⁻¹·min⁻¹. The difference between directly measured VO₂max (38.95±3.81 mL·kg⁻¹·min⁻¹ in males, 35.90±3.46 mL·kg⁻¹·min⁻¹ in females) and predicted VO₂max or PVO₂max (38.87±1.15 mL·kg⁻¹·min⁻¹ in male and 36.24±1.94 mL·kg⁻¹·min⁻¹ in females) from HRpeak·HRrest⁻¹ was statistically insignificant. Replacement of HRpeak with age-predicted maximum heart rate or HRmax depicted the estimated VO₂max or EVO₂max value of 37.72±2.55 mL·kg⁻¹·min⁻¹ in males and 37.20±1.50 mL·kg⁻¹·min⁻¹ in females which were also insignificantly different from the directly measured VO₂max value. The proportionality factor between VO₂max and HRmax·HRrest⁻¹ obtained in the males (15.01±1.13 mL·kg⁻¹·min⁻¹) and the females (14.56±1.19 mL·kg⁻¹·min⁻¹) were also close to the theoretical value of under 15 mL·kg⁻¹·min⁻¹.

Correlation statistics revealed a significant (P<0.001) relationship of VO₂max with PVO₂max (r=0.87 in males and r=0.58 in females) and EVO₂max (r=0.83 in males and r=0.79 in females). The regression lines obtained from these significant correlations were plotted in Figs. 1, 2, 3 and 4. The standard errors of estimate (SEE) of VO₂max when predicted from HRpeak·HRrest⁻¹ and HRmax·HRrest⁻¹ were 1.87 mL·kg⁻¹·min⁻¹ and 2.14 mL·kg⁻¹·min⁻¹, respectively in males (Figs. 1 and 2) and 2.09 mL·kg⁻¹·min⁻¹ and 2.83 mL·kg⁻¹·min⁻¹, respectively in females (Figs. 3 and 4).
Fig. 1. Relationship between maximum oxygen uptake and \( \text{HR}_{\text{max}} \cdot \text{HR}_{\text{rest}}^{-1} \) in sedentary male Indian university students.

\[ Y = 19.61 X - 10.36, \quad r = 0.87, \quad p<0.001 \]
\[ \text{SEE} = 1.87 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1} \]

Fig. 2. Relationship between maximum oxygen uptake and \( \text{HR}_{\text{max}} \cdot \text{HR}_{\text{rest}}^{-1} \) in sedentary female Indian university students.

\[ Y = 20.05 X - 13.83, \quad r = 0.58, \quad p<0.001 \]
\[ \text{SEE} = 2.83 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1} \]
Fig. 3. Relationship between maximum oxygen uptake and $\text{HR}_{\text{peak}} \cdot \text{HR}_{\text{rest}}^{-1}$ in male sedentary university students.

Fig. 4. Relationship between maximum oxygen uptake and $\text{HR}_{\text{peak}} \cdot \text{HR}_{\text{rest}}^{-1}$ in sedentary female Indian university students.
Fig. 5. Plotting of difference between \( \dot{V}O_{2\text{max}} \) and \( P\dot{VO}_{2\text{max}} \) against their mean to test the limit of agreements for measured versus predicted \( \dot{V}O_{2\text{max}} \) in sedentary male Indian university students.

Fig. 6. Plotting of difference between \( \dot{V}O_{2\text{max}} \) and \( P\dot{VO}_{2\text{max}} \) against their mean to test the limit of agreements for measured versus predicted \( \dot{V}O_{2\text{max}} \) in female sedentary university students.
Fig. 7. Plotting of difference between $\dot{V}O_{2\text{max}}$ and $E\dot{V}O_{2\text{max}}$ against their mean to test the limit of agreements for measured versus estimated $V_{O2\text{max}}$ in sedentary male Indian university students.

Fig. 8. Plotting of difference between $\dot{V}O_{2\text{max}}$ and $E\dot{V}O_{2\text{max}}$ against their mean to test the limit of agreements for measured versus estimated $V_{O2\text{max}}$ in sedentary female Indian university students.
Application of the prediction norms in the confirmatory group revealed insignificant difference of $\dot{V}O_{2\text{max}}$ (38.84±3.83 ml·kg$^{-1}$·min$^{-1}$) from $P\dot{V}O_{2\text{max}}$ (38.99±3.68 ml·kg$^{-1}$·min$^{-1}$) and $E\dot{V}O_{2\text{max}}$ (38.39±3.66 ml·kg$^{-1}$·min$^{-1}$). Analyses of data by the Bland and Altman method of limit of agreement analysis has been plotted for $P\dot{V}O_{2\text{max}}$ (Figs. 5 and 6) and $E\dot{V}O_{2\text{max}}$ (Figs. 7 and 8).

**DISCUSSION**

Uth et al. (2004) derived the equation to predict $\dot{V}O_{2\text{max}}$ from the ratio of $HR_{\text{peak}}$ or $HR_{\text{max}}$ with $HR_{\text{rest}}$. The results recommended to use the equations as a simple and useful tool to predict $\dot{V}O_{2\text{max}}$, subject to proper validation of the conversion factor in a specific population. Such a prediction technique would enable to bypass the complicated, hazardous, exhaustive, time-consuming and expensive protocol of direct $\dot{V}O_{2\text{max}}$ estimation by predicting the $\dot{V}O_{2\text{max}}$ based only on the resting measurements alone.

In the present study, the conversion factors obtained from the “study group” were 15.47±0.80 ml·kg$^{-1}$·min$^{-1}$ and 15.01±1.13 ml·kg$^{-1}$·min$^{-1}$ in males and 14.90±0.96 ml·kg$^{-1}$·min$^{-1}$ and 14.56±1.19 ml·kg$^{-1}$·min$^{-1}$ in females while using the $HR_{\text{peak}}$/$HR_{\text{rest}}$ and $HR_{\text{max}}$/$HR_{\text{rest}}$, respectively. The values in both the genders were not significantly different from the theoretically assumed value of under 15ml·kg$^{-1}$·min$^{-1}$. Moreover, correlation statistics revealed a significant (p<0.001) relationship of $\dot{V}O_{2\text{max}}$ with $HR_{\text{max}}$/$HR_{\text{rest}}$ ($r=0.83$ in males and $r=0.79$ in females respectively) and $HR_{\text{peak}}$/$HR_{\text{rest}}$ ($r=0.87$ in males and $r=0.58$ in females, respectively). The regression statistics computed the norms for prediction of $\dot{V}O_{2\text{max}}$ from $HR_{\text{max}}$/$HR_{\text{rest}}$ and $HR_{\text{peak}}$/$HR_{\text{rest}}$ in the currently studied population (Figs. 1, 2, 3 and 4). The standard errors of estimate (SEE) were 2.14 ml·kg$^{-1}$·min$^{-1}$ and 1.87 ml·kg$^{-1}$·min$^{-1}$, respectively in males and 2.09 ml·kg$^{-1}$·min$^{-1}$ and 2.83 ml·kg$^{-1}$·min$^{-1}$, respectively in females which were 5.5%, 4.8%, 5.8% and 7.9% of the corresponding mean value of $\dot{V}O_{2\text{max}}$. Such SEEs were substantially small and well comparable with the data of other indirect tests (Fox, 1973; Åstrand and Rhyming, 1954). Moreover, the SEE values were superior to some other relevant studies (Kline et al., 1987). Uth et al. (2004) reported a SEE value of 2.72 ml·kg$^{-1}$·min$^{-1}$ while evaluating the same procedure in trained men of Denmark. In another study, Uth (2005) reported a SEE value of 3.57 ml·kg$^{-1}$·min$^{-1}$.

In order to enumerate the validity of the prediction norms in the present population, the regression equations were applied in the “confirmatory group” (n=40). The Bland and Altman method of limit of agreement analysis (Bland and Altman, 1986) revealed that in the case of the male group, the limits of agreement were -0.03 to 2.13 ml·kg$^{-1}$·min$^{-1}$ and -0.59 to 2.55 ml·kg$^{-1}$·min$^{-1}$ for $\dot{V}O_{2\text{max}}$ and $E\dot{V}O_{2\text{max}}$, respectively (Figs. 5 and 6). In the case of females limits of agreement were 0.04 to 2.12 ml·kg$^{-1}$·min$^{-1}$ and 0.62 to 2.52 ml·kg$^{-1}$·min$^{-1}$ for $P\dot{V}O_{2\text{max}}$ and $E\dot{V}O_{2\text{max}}$, respectively. Such differences in the limit of agreement correspond to about 5.4 to 6.7% of the respective mean values obtained in the confirmatory group. Moreover, in the confirmatory group, the entire individual values of difference between $\dot{V}O_{2\text{max}}$ and $E\dot{V}O_{2\text{max}}$ as well as between $\dot{V}O_{2\text{max}}$ and $P\dot{V}O_{2\text{max}}$ were within the range of mean±2SD (Figs. 5, 6, 7, 8). Such finding further established the good agreement between the direct test and indirect tests.

Chapman et al. (1960) reported that the ratio between the maximum and resting stroke volume (SV) changes with change in resting posture (supine, sitting and standing). SVmax-to-SVrest ratio is about 1.3 and 1.8 in supine and standing posture, respectively. Therefore, the measurement of resting heart rate should be done under strict standardized conditions for prediction of $\dot{V}O_{2\text{max}}$ by using the heart rate ratio method. It also emphasizes that the proportionality factors should first be experimentally established before the principle is extended to other populations with difference in age, sex and training status. Determination of $\dot{V}O_{2\text{max}}$ from $HR_{\text{rest}}$ and age-predicted $HR_{\text{max}}$ would facilitate the accomplishment of the test and potentially increase its applicability to groups of individuals where maximal effort may be unwarranted, e.g. patients or elderly individuals.

Body height, body mass, peak heart rate and the directly estimated and indirectly predicted values of $\dot{V}O_{2\text{max}}$ were significantly higher in males than in females although both the groups had insignificant difference in age. As far as the values of correlation coefficients were concerned, the values were higher in
males than their female counterparts. However, the physiological basis of existence of such higher values of the correlation coefficient in male groups is beyond the scope of this research and may be explored in further detailed studies.

CONCLUSION

The values of proportionality factors determined from $HR_{peak}/HR_{rest}^{-1}$ or $HR_{max}/HR_{rest}^{-1}$ were close to the theoretical value of under 15 ml·kg$^{-1}$·min$^{-1}$. Prediction of $\dot{V}O_2_{max}$ from $HR_{max}/HR_{rest}^{-1}$ and $HR_{peak}/HR_{rest}^{-1}$ depicted substantially small SEE values which were superior to or well comparable with other indirect tests. Furthermore, from the good agreement between the directly and indirectly measured values of $\dot{V}O_2_{max}$, it was concluded that the principle of the test may provide a simple and useful tool for $\dot{V}O_2_{max}$ estimation in the studied population, i.e., in healthy sedentary Indian university students.

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