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Heart-rate-based prediction of velocity at lactate threshold in ordinary adults

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ABSTRACT

Background: Velocity lactate threshold (VLT) is commonly used as a standard for exercise intensity, although previous studies of VLT have focused mostly on well-trained athletes. Heart rate (HR) is an important physiological index which is easy to measure, the heart rate-workload relationship curve is the reported coincidence with lactate threshold (LT). This study aimed to develop valid, simple and economical velocity at lactate threshold prediction methods for general Chinese adults.

Methods: Eighty-four Chinese adults (49 males and 35 females aged 27.1 ± 8.3 years) were recruited to perform a graded exercise test on a treadmill. A 20-s rest time for the blood sample collection was set between each 3-min successive stage. Blood lactate concentration and heart rate (HR) were determined using a blood lactate analyser and HR monitors. Multiple linear regressions were applied to develop VLT prediction models using velocity at different HR levels, genders, BMI and ages as dependent variables.

Results: Eight VLT prediction models were established, in which 47%–65% of variance of VLT could be explained. The results of the paired t-tests showed no significant difference can be observed between estimated and measured VLTs.

Conclusion: In conclusion, simple and convenient VLT prediction models were established, and the models are valid in predicting VLT for general population.

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Introduction

In incremental exercise, an abrupt intensity increase in either muscle or blood lactate is called lactate threshold (LT) and the intensity at the LT represents the maximal intensity in which steady-state exercise can be maintained.¹ Velocity at LT (VLT) plays an important role in the physical activities of ordinary people. Participation in regular physical activity can ameliorate the metabolic abnormalities associated with obesity.² Therefore, as the turning point of aerobic exercises to anaerobic exercises,³ LT can be employed in exercise prescription for a special population requiring controlled exercise intensity.

VLT is an important indicator of aerobic endurance. Previous research has shown that VLT is a good predictor of endurance

running performance.⁴ However, the number of studies on VLT in untrained population are far less compared to well-trained athletes because direct measurement of LT is invasive and time consuming.⁵ Several studies have proposed various non-invasive prediction methods.^{6,7} However, these predictive studies were limited to competitive sports. To date, non-invasive prediction measures of VLT in untrained population have not been reported.

Heart rate (HR) is an important physiological indicator which is easy to measure. During progressive incremental exercise testing, the heart rate-workload relationship curve is manifested visually as a curvilinear response. The deflection is called 'heart rate deflection point (HRDP)' or 'heart rate threshold'.⁸ HRDP is the reported coincidence with the 'anaerobic threshold', which more conventional terminology designates as the LT.^{9,10} Thus, HRDP is treated as a testing method using non-invasive parameters to assess LT. Some individuals found that HRDP usually occurs close to 90% of the maximal heart rate (HRmax).¹¹ However, HRmax is obtained by a maximal continuous incremental test until participants can no longer maintain the required speed, thus, is very difficult for ordinary population to achieve. As a result, they choose the prediction

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Table 1
Participants' physical characteristics.

| | Men (n = 49) | Women (n = 35) | Total (n = 84) |
|-------------|--------------------|----------------|----------------|
| Age (y) | 28(8) ^a | 24.4 (5.0) | 26.4 (7.0) |
| Height (cm) | 175.2 (5.8) | 162.2 (5.5) | 169.8 (8.6) |
| Weight (kg) | 70.1 (8.7) | 53.0 (5.0) | 63.0 (11.2) |

^a Mean (standard deviation).

Table 2
The prediction models for VLT.

| Models (n = 60) | Variables | B | t | R ² | Adjusted R ² | REE |
|-----------------|------------|------|--------|----------------|-------------------------|------|
| Model 1 | Constant | 1.95 | | .65 | .64 | 1.49 |
| | Gender | -.55 | -1.35* | | | |
| | V160 | .87 | 9.32* | | | |
| Model 2 | Constant | 1.87 | | .64 | .63 | 1.51 |
| | Gender | -.50 | -1.20 | | | |
| | V90% HRmax | .75 | 9.07* | | | |

Gender: 0 for men and 1 for women.

V160: Velocity at heart rate of 160.

V90% HRmax: Velocity at 90% maximal heart rate.

*: $P < .05$.

formula of HRmax ($\text{HRmax} = 220 - \text{age}$) to guide the daily fitness; however, the validity of this formula has often been questioned.¹² Therefore, the aim of this study was to find a simple way to predict VLT in ordinary population.

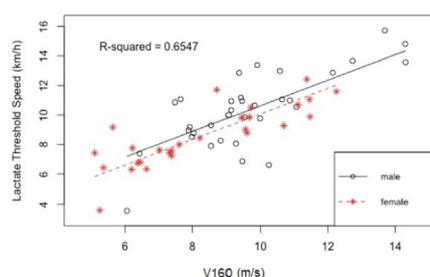
Materials and methods

Participants

Eighty-four Chinese adults (49 males and 35 females) took part in this study by recruitment through an online advertisement (age 27.1 ± 8.3 years).¹³ 'Untrained' was defined as individuals who had never initiated an endurance running training regime.¹⁴ The study was approved by the Ethics Committee of College of Education at Zhejiang University.

Procedures

Participants performed a graded exercise test on a treadmill. The initial speed was set as $2 \text{ m} \cdot \text{s}^{-1}$ for men, whereas $1.75 \text{ m} \cdot \text{s}^{-1}$ for women. The speed increased by $0.5 \text{ m} \cdot \text{s}^{-1}$ for each stage, and the exercise lasted 3 min for each stage. A 20-s rest time for the blood sample collection was set between each stage. The criteria for the termination of the test were (i) blood lactate concentration $\geq 4 \text{ mmol L}^{-1}$ and $\text{HR} \geq 90\% \text{ HRmax}$ and (ii) any participant who suffered from physical discomfort and could not continue the test.



Measurement

In this study, $20 \mu\text{L}$ of fingertip blood sample was collected from the participants with a sterilized blood-sampling needle during the rest time between stages. Blood lactate concentration was determined automatically with these samples using a blood lactate analyser (Lactate scout; EKF, Germany). The analyser was calibrated according to the instrument manual before each test. During the exercise test, the HR of the participants was recorded from the beginning to the end of the test with HR monitors (Polar H7; Polar Electro Oy, Kempele, Finland).

Data analysis

The 4 mmol L^{-1} was calculated through interpolation method to form a curve of the blood lactate and running velocity to obtain the VLT.15 Linear equations were established based on the measured HR and velocity during the test. The velocity at HR of 130beats/min (V130) was calculated by using the established equation, and V140, V150 and V160 were calculated with the same method. According to the HRmax formula, 90% HRmax of the participants was substituted to the corresponding equations to calculate the velocity at 90% HRmax (V90%), V85%, V80% and V75%.

Data on the participants were assigned randomly to two groups: 60 participants in the model development (MD group) and 24 in the cross-validation groups (CV group). Multiple linear regressions were applied to develop VLT prediction models using velocity at different HR levels, genders, BMI and ages that served as dependent variables based on the data of the MD group. Bland–Altman analyses were used on the data of the CV group to check the degree of consistency between the prediction model and actual value.

Results

The descriptive characteristics of the participants are presented in Table 1. A total of 49 men and 35 women were included in the data analysis.

Table 2 and Fig. 1 show that eight VLT prediction models were established in this study, although age and BMI were not significant. Only two models were placed in the Table 2, while the rest are

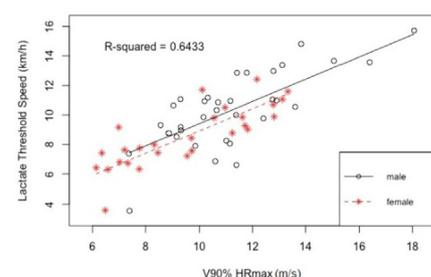
Table 3
The cross-validation of prediction models.

| Models (n = 24) | RMSE | P ^a | Predictive value | Error percentage |
|-----------------|------|----------------|--------------------------|------------------|
| Model 1 | 1.87 | 0.12 | 10.00(1.86) ^b | 20.2% |
| Model 2 | 1.99 | 0.16 | 9.99(1.90) ^b | 19.5% |

RMSE: Root mean squared error.

^a P: Paired *t*-test *p* value.

^b Mean (standard deviation).

**Figure 1.** Different VLT prediction model.
V160: Velocity at heart rate of 160. V90% HRmax: Velocity at 90% maximal heart rate.

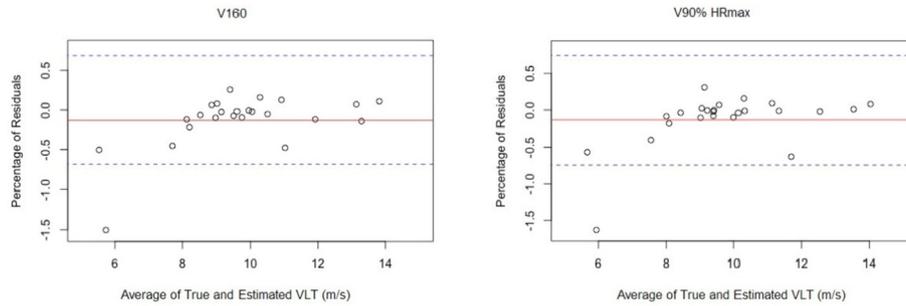


Fig. 2. Bland-Altman plot comparing the residuals and measured. VLT. V160: Velocity at heart rate of 160. V90% HRmax: Velocity at 90% maximal heart rate.

presented in Appendix A. Results indicated that 47%–65% of the variance of VLT could be explained by the velocities at different HR levels. When the eight models were compared, Model 1, in which V160 was utilized as the dependent variable, had the highest R^2 (0.65) and the lowest residual standard error (RSE) (1.51). By contrast, the models using velocity at a relatively lower HR demonstrated lower R^2 and higher RSE.

Table 3 and Fig. 2 show that the data of the CV group were applied to determine the validity of the prediction models, the rest results are presented in Appendix B and C. The paired *t* tests showed that no significant difference was observed between the estimated and measured VLTs. The Bland–Altman plots (Fig. 2 and Appendix D) showed the error percentages of these prediction models ranged from 19.5% to 24.9%.

Discussion

Different criteria for independent variables led to different results. Regression results showed that 47%–65% of the variance could be explained by the models and the CV data implied that the errors of different models were approximately 20%, showing that only a slight difference existed between the models with velocity at relative and absolute HRs. In these eight models, those using velocity at high HR presented good prediction effects. Previous studies suggested that LT appeared at 90% HRmax,⁸ whereas in this study, the HR when the blood lactate concentration deflects should be 175.8 ± 9.3 beats/min, which was similar to the HR required in Model 1. For the ordinary population, we suggested utilising the model that required lower HR, even if these models have a slightly lower R^2 , the velocity at lower HR could be easily achieved, the models with velocity at lower HR maybe applied more frequently due to their better applicability.

The prediction of VLT should be used widely in the ordinary population, although traditional LT tests require professional staff and equipment to conduct multiple blood collection. LT correlates better with endurance running performance; however, an important issue in their training plan is how to determine their running pacescientifically.^{16,17} The current study is one of the few to focus on non-invasive LT prediction models with HR as predictors. HR could be monitored easily and conveniently during sports training through HR chest belts, smart watches or smart bracelets.¹⁸ Through the developed algorithm in this study, the VLT could be estimated with measured HR, which could be applied widely in the daily fitness activities of ordinary people.

Several limitations should be acknowledged in the data interpretation of this study. This study set the blood lactate concentration at 4 mmol L^{-1} , but inter-individual difference was not considered in Fixed blood lactate concentration. The inter-individual difference can be reduced in future studies, although

the blood lactate concentration at 4 mmol L^{-1} is considered to be the most widely applied indicator in sports training. The relatively small sample size may be considered as another limitation of this study, although most similar studies have no more than 30 participants.¹⁹ The sample size of this study is acceptable for the development and cross validation of the prediction models. Despite these limitations, several simple and convenient prediction models were established and found to be valid in predicting VLT for ordinary Chinese adults.

Conclusion

Simple and convenient VLT prediction models were established and the models were found to be capable of validly predicting VLT for the general population.

Acknowledgement

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Appendix A. The prediction models for VLT

| Models (n = 60) | Variables | B | t | R^2 | Adjusted R^2 | REE |
|-----------------|------------|-------|--------|-------|----------------|------|
| Model 3 | Constant | 5.43 | | .47 | .45 | 1.83 |
| | Gender | -1.48 | -3.08* | | | |
| Model 4 | V130 | .88 | 6.07* | .56 | .54 | 1.68 |
| | Constant | 3.90 | | | | |
| | Gender | -1.14 | -2.57* | | | |
| Model 5 | V140 | .88 | 7.44* | .62 | .61 | 1.56 |
| | Constant | 2.70 | | | | |
| | Gender | -.82 | -1.95* | | | |
| Model 6 | V150 | .90 | 8.60* | .56 | .55 | 1.67 |
| | Constant | 3.67 | | | | |
| | Gender | -1.57 | -2.63* | | | |
| Model 7 | V75% HRmax | .85 | 7.56* | .61 | .60 | 1.57 |
| | Constant | 2.72 | | | | |
| | Gender | -.88 | -2.09* | | | |
| Model 8 | V80% HRmax | .85 | 8.43* | .64 | .62 | 1.52 |
| | Constant | 2.14 | | | | |
| | Gender | -.66 | -1.59 | | | |
| | V85% HRmax | .81 | 8.92* | | | |

Gender: 0 for men and 1 for women.

V130 (140,150): Velocity at heart rate of 130 (140,150).

V85% (80%,75%) HRmax: Velocity at 85% (80%,75%) maximal heart rate.

*: $P < .05$.

Appendix B. The cross-validation of prediction models

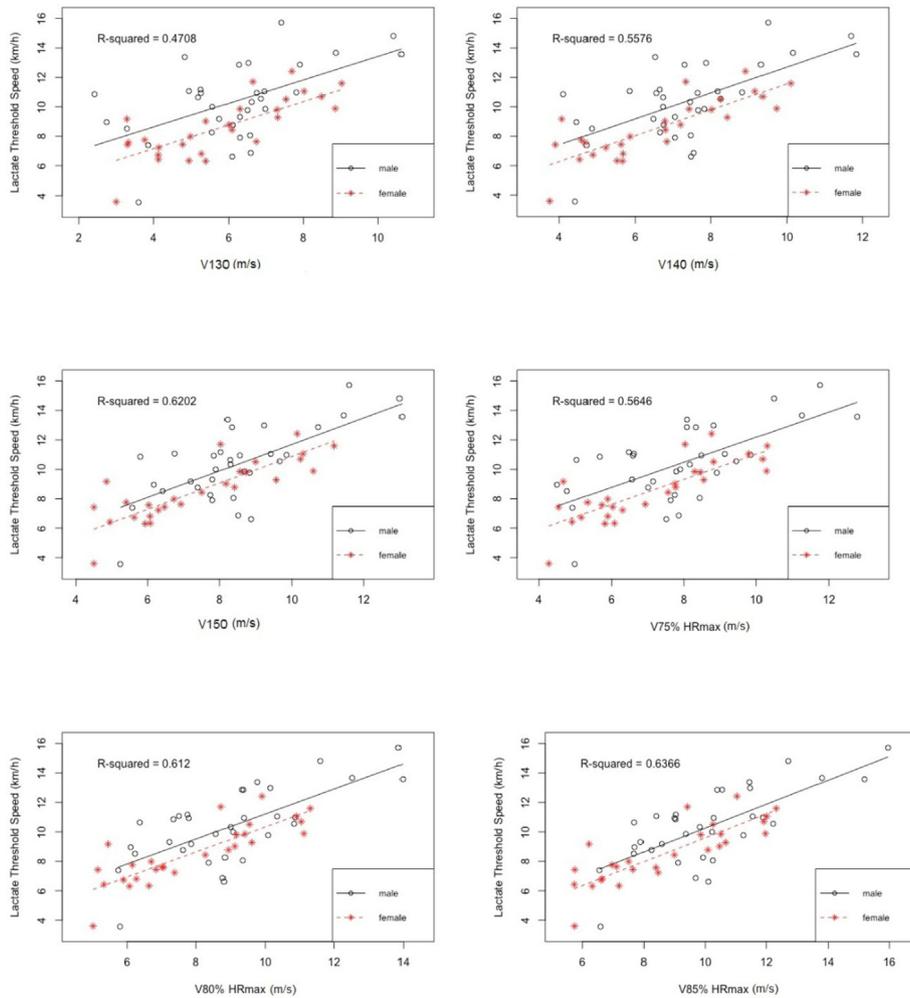
| Models (n = 24) | RMSE | P [£] | Predictive value | Error percentage |
|-----------------|------|----------------|-------------------------|------------------|
| Model 3 | 2.24 | 0.53 | 9.71(1.63) [§] | 24.9% |
| Model 4 | 2.04 | 0.36 | 9.80(1.69) [§] | 22.9% |
| Model 5 | 1.91 | 0.21 | 9.91(1.77) [§] | 21.3% |
| Model 6 | 2.16 | 0.46 | 9.75(1.80) [§] | 23.5% |
| Model 7 | 2.04 | 0.32 | 9.84(1.83) [§] | 21.7% |
| Model 8 | 1.99 | 0.22 | 9.92(1.87) [§] | 20.2% |

£: Paired t-test p value.

§: Mean (standard deviation).

RMSE: Root mean squared error.

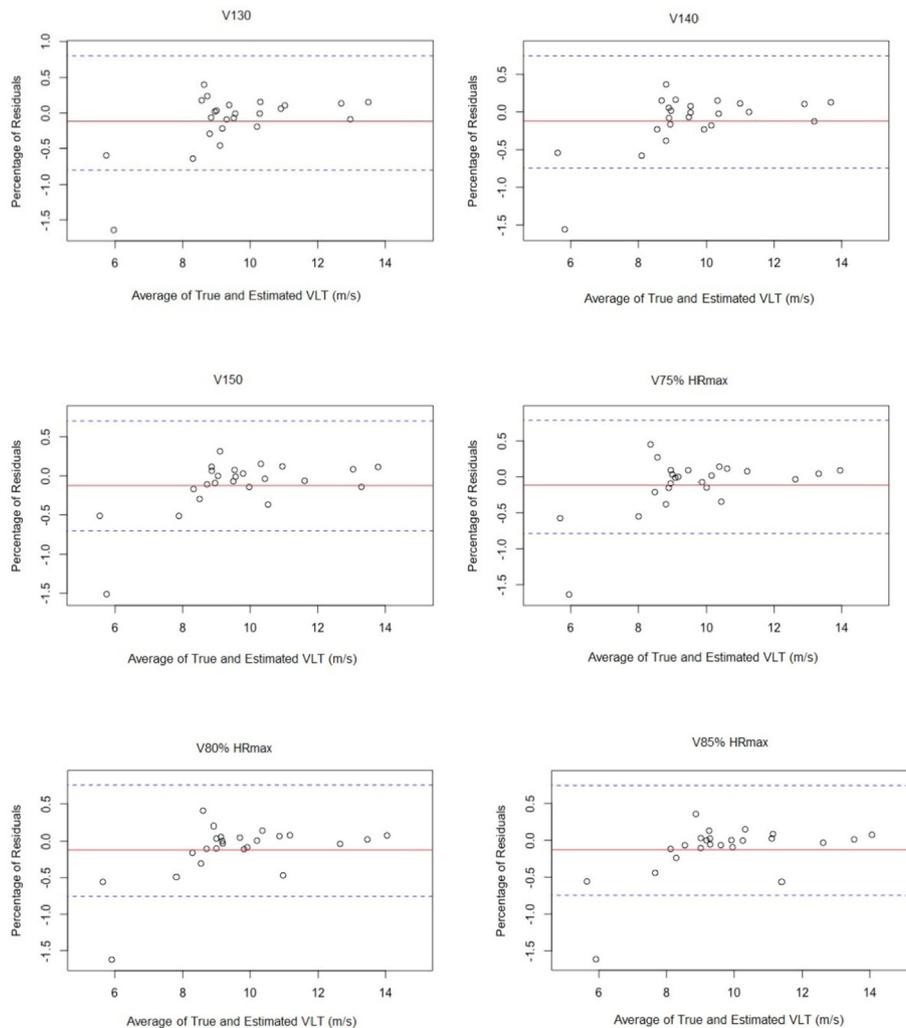
Appendix C. Different VLT prediction model



V130 (140,150): Velocity at heart rate of 130 (140,150).

V85% (80%,75%) HRmax: Velocity at 85% (80%,75%) maximal heart rate.

Appendix D. Bland-Altman plot comparing the residuals and measured VLT



V130 (140,150): Velocity at heart rate of 130 (140,150).

V85% (80%,75%) HRmax: Velocity at 85% (80%,75%) maximal heart rate.

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