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Original Article

Creating linear models to estimate maximal oxygen uptake in male youth from Delhi: residing in low-altitude habitat

Mahesh Sharma[1]*, Sajjad Ahmad Bhat[2], Mayank Kaushik[3], Sharubam Bidyaluxmi Devi[4]

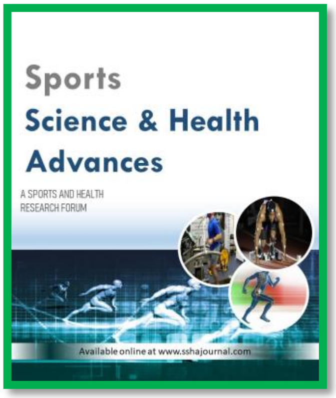
[1]Lecturer Physical Education in Directorate of Education, New Delhi, India

[2]Assistant Students Welfare Officer, Sher-i-Kashmir University of Agricultural Science and Technology, Shalimar, Srinagar, Kashmir, India

[3]Research Scholar, Department of Physical Education and Sports Sciences, University of Delhi, New Delhi, India

[4]Research Scholar, Department of Physical Education and Sports Sciences, Manipur University Canchipur Imphal East, India

***Correspondence**: mahi07mahesh07@gmail.com



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Abstract

The objective of this research was to formulate linear models for predicting Maximal Oxygen Uptake (VO2 Max.) in male youth residing in Delhi. The study involved seventy-five healthy male individuals from Delhi, with an average altitude of 744 feet (127 meters). The age range of the participants was between 17 to 25 years. Submaximal bench step tests were administered to the youth following the American College of Sports Medicine Protocol, aiming to determine the VO2max. (dependent variable). This was achieved by plotting HR-workload combinations calculated through the Karvonen heart rate reserve method. Data collection was carried out using a Cardio-Sport heart rate monitor and the step test protocol. Various independent variables were selected, including Age, Body weight in kilograms (B.Wt.), Height in centimeters (Ht.), Resting Heart Rate (RHrest), Target Heart Rate (THR), Maximal Heart Rate (HRmax.), Heart Rate at Two minutes of step testing with a cadence of 15 steps/min (ExHR2), Heart Rate at Four minutes of step testing with a cadence of 20 steps/min (ExHR4), Heart Rate at Six minutes of step testing with a cadence of 30 steps/min (ExHR6), recovery heart rate at one minute of rest (RcvHR1), recovery heart rate at two minutes of rest (RcvHR2), and recovery heart rate at the third minute of rest (RcvHR3) – following the formula recommended by the American College of Sports Medicine. The collected data underwent statistical analysis, including mean, standard deviation, correlation matrix, and linear regressions using SPSS to derive linear models. The study concluded by establishing ten independent linear models, with model number six (M6) identified as the most effective for estimating the VO2 max. of youth in Delhi.

Keywords: maximal oxygen consumption, heart rate, step testing, aerobic fitness, regression analysis, linear models

Introduction

VO2 max, also known as maximal oxygen consumption, peak oxygen uptake, or maximal aerobic capacity, represents the highest rate of oxygen consumption observed during incremental exercise, typically assessed on a motorized treadmill or a bench step test (Dlugosz 2013). It serves as a crucial indicator of an individual's aerobic physical fitness and significantly influences their endurance capacity. The term is derived from V = volume, O2 = oxygen, and max. = maximum.

VO2 max is expressed either as an absolute rate (e.g., liters of oxygen per minute - L/min) or as a relative rate (e.g., milliliters of oxygen per kilogram of body mass per minute - ml/kg/min), commonly used to compare the performance of endurance sports athletes. However, it is noted that VO2 max does not necessarily vary linearly with body mass (Wikipedia, July 2017).

Crucially, VO2 max plays a vital role in determining cardio-respiratory fitness and aerobic performance. Measured in ml/min/kg, it signifies the maximum amount of oxygen utilized during intense physical activity, reflecting the efficiency of cells in using oxygen for energy (Tipton, 1977). Various methods exist to measure VO2 max, with some requiring sophisticated equipment. The step test, incorporating heart rate recordings and following the Karvonen formula for a step testing protocol, is considered a quick, easy, and safe way to estimate VO2 max (Practical Math for Health Fitness Professionals, 1996).

Heart rate, the number of cardiac contractions per minute, is influenced by factors such as exercise, training, age, sex, disease, stress, temperature, and altitude. While 72 beats per minute (bts/min) is generally considered normal, trained individuals often exhibit lower resting heart rates. The Autonomic Nervous System controls heart function during exercise, with parasympathetic withdrawal causing an increase in heart rate during mild to moderate exercise and sympathetic activity mediating the rise during strenuous exercise (Lewis 1980).

Endurance athletes typically display resting bradycardia, a phenomenon not conclusively explained but possibly attributed to a combination of factors, including a reduction in the intrinsic rate of the heart, decreased sympathetic tone, and increased parasympathetic tone (Machiel 1985). Maximal heart rate is viewed as an upper limit for central cardiovascular function, with decades of research supporting its existence (Robert 2008).

Regular exercise induces adaptive changes in cardiac function, physical performance, and oxygen uptake capacity. Physically trained individuals exhibit higher maximal oxygen uptake capacity compared to their untrained counterparts (Heyward, 1997). The developed regression models hold potential for meeting the diverse requirements of VO2 max adaptation in various games, sports, or physical activities.

Recent research underscores the validity of the Queens College step test in estimating VO2max. Altitude is shown to impact aerobic capacity, with a reduction in steptest performance observed at higher altitudes (Tiaira Bates, 2015).

Among physiological conditions, strenuous exercise has a pronounced effect on blood pressure (BP). BP is commonly used to assess cardiovascular system functioning, with well-trained individuals displaying faster HR changes during and after exercise compared to untrained individuals (Astrand, 1984).

The "recovery heart rate" signifies the heart's ability to return to normal levels after physical activity, providing insight into fitness level and heart function. A healthy heart will recover more quickly than one that is not accustomed to regular exercise, potentially indicating underlying cardiovascular issues if recovery is delayed.

First Minute of Recovery

The first minute of recovery is the most crucial. After exercise, heart rate experiences an abrupt drop during the first minute. This recovery period can indicate fitness level and give an early warning of potential heart problems. In a recent study performed by the Cleveland Clinic Foundation classified a heart rate decrease of 12 beats or less in the first minute as abnormal. The study also reported that people with an abnormal decline in heart rate had a greater chance of mortality in the subsequent six years due to heart problems. (The New England Journal of Medicine, October 1999).

Two-Minute Recovery:

The heart rate two minutes after exercise is referred to as the recovery heart rate. This is the most common measurement in determining cardiovascular fitness. To test for improvements, record the working heart rate during exercise, then record recovery heart rate at the two-minute mark. Subtract the two-minute recovery rate from the working heart rate to determine a baseline for improvement. For example, if working levels were 150 beats per minute and the two-minute recovery rate was 95, then 55 is the recovery heart rate.(Apr 23,2015)

Recovery heart rate is simply your pulse rate after exercise. Some fitness specialists refer to it as post-exercise heart rate. The pulse number is used for different reasons in different settings. Recovery heart rate is also used in popular fitness tests like the YMCA Submaximal StepTest. During the fitness assessment, an exerciser steps up and down on a 12-inch box at a rate of 24 steps per minute. The test lasts for three minutes. Recovery heart rate is measured for one full minute immediately following the test.

It is summarized that at altitudes over 5000 feet (1524 meters), the ability to perform physical work is decreased due to hypoxia (lowered PO2). However, healthy high altitude dwellers show excellent adaptation to their environment. These adaptations are likely to be associated with altered gene expression as the expression of genes associated with vascular control and reactions to hypoxia have been found to be high in altitude dwellers (Appenzeller2006). Blood volumes are larger in high altitude dwellers. This is due to a large packed cell volume whereas at sea levels plasma volume was found to be large. Probably as the result of the large blood volumes, tolerance to orthostatic stress was greater than that in sea-level residents (Claydon, 2005). The Purpose of the study was to develop linear models in regard to maximal oxygen uptake (VO2 max.) of low altitude Delhi male youth, which will be useful for evaluation, grading, grouping and monitoring the aerobic fitness.

Methodology

The research involved a cohort of seventy-five healthy male youth from Delhi, situated at an altitude of 744 feet/127 meters. The age range of the participants spanned from 17 to 25 years. To assess their Maximal Oxygen Uptake (VO2 max.), the youth underwent a submaximal bench step test. This involved plotting HR-workload combinations determined through the Karvonen heart rate reserve method. Key cardio-circulatory variables, including Resting Heart Rate (HRrest), Target Heart Rate (THR), Maximal Heart Rate (HRmax.), Heart Rate at Two minutes of step testing with a cadence of 15 steps/min (ExHR2), Heart Rate at Four minutes of step testing with a cadence of 20 steps/min (ExHR4), Heart Rate at Six minutes of step testing with a cadence of 30 steps/min (ExHR6), recovery heart rate at one minute of rest (RcvHR1), recovery heart rate at two minutes of rest (RcvHR2), and recovery heart rate at the third minute of rest (RcvHR3), were selected for measuring VO2 Max, following the American College of Sports Medicine's recommended method. Submaximal exercise testing was employed to estimate VO2 max by leveraging the linear relationship between heart rate responses and workload VO2 values. This relationship was considered by plotting HR-workload combinations calculated using the Karvonen heart rate reserve method (Practical Math for Health Fitness Professionals, 1996).

The statistical analysis involved mean calculation, standard deviation, correlation matrix, and linear regression to develop linear models using SPSS.

Findings

According to table no 2, the VO2 max. significantly correlated to ExHR4 ($r = -.537$). The body weight highly correlates to Ht. ($r = .696$). Heart Rate Rest (HRrest) significantly correlates to ExHR2 ($r = .325$), ExHR4 ($r = .371$), RcvHr1 ($r=.496$), RcvHr2 ($r=.600$), RcvHr3($r=.688$). ExRH2 significantly correlates to ExHR4 ($r = .559$), ExHR6 ($r = .503$). ExRH6 significantly correlates to RcHR1 ($r = .628$), RcHR1 ($r = .607$), RcHR3 ($r = .575$), RcvHR1 highly correlates with RcvHR2 ($r = .902$) and RcvHR3 ($r =.826$). RcvHR 2 highly correlates with RcvHR3 ($r = .915$).

A Partial Regression Plot of dependent variable: VO2max. with ExHR4 (heart rate at four minutes of exercise) has been graphically represented in the figure below:-

Table 1 Descriptive Statistics of the selected variables of the subjects

Sr.No	Variable Name	Symbol	Mean	S.D
1	Age (Years)	AGE	19.97	2.04
2	Body weight (Kgs)	B wt.	64.04	10.18
3	Height (cms)	Ht.	171.65	8.18
4	Maximal Oxygen Uptake(ml/kg/min)	VO2max.	50.76	4.12
5	Resting Heart rate (bts/min)	HRrest	62.43	7.94
6	Heart rate at 2 mins of exercise (bts/min)	ExHR2	123.09	11.03
7	Heart rate at 4 mins of exercise(bts/min)	ExHR4	142.64	6.59
8	Heart rate at 6 mins of exercise(bts/min)	ExHR6	173.21	12.46
9	Recovery heart rate at 1 min (bts/min)	RcvHR1	118.56	18.77
10	Recovery heart rate at 2 min (bts/min)	RcvHR2	99.55	17.99
11	Recovery heart rate at 3 min (bts/min)	RcvHR3	92.17	16.15

N=75

Table 2 Pearson Correlation Among Selected Variables of Habitat of Low Altitude Delhi Male Youth

	VO2max	Bwt	Ht.	HRrest	Ex.HR2	Ex.HR4	Ex.H6	RcvHR1	RcvHR2	RcvHR3	AGE
VO2max	1	.126	.133	-.076	.131	.537	.005	.080	.066	.063	.113
B.wt.		1	.696	.029	.210	.124	.018	.328	.278	.235	.261
Ht.			1	-.053	.155	.147	.053	.173	.169	.070	.110
HR rest				1	.325	.371	.277	.496	.600	.688	-.054
Ex.HR2					1	.559	.503	.403	.437	.468	-.092
Ex.HR4						1	.472	.433	.454	.463	-.093
Ex.HR6							1	.628	.607	.575	.080
RcvHR1								1	.902	.826	.091
RcvHR2									1	.915	.066
RcvHR3										1	.038
Age											1

*Significant at 0.05 level

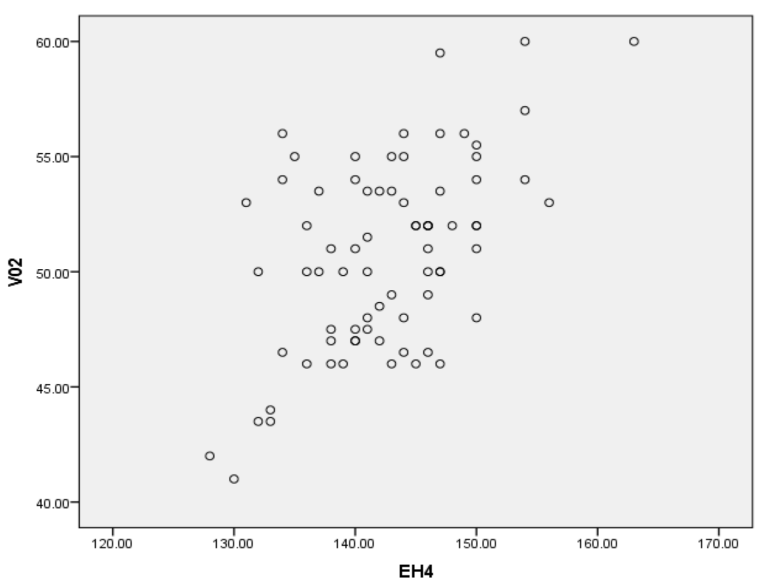

Figure 1 Partial regression plot between Dependent variable vo2 max and independent variable Eh4 as best predictor

Table 4 Linear Models Developed for Estimating VO2 Max. of Delhi Male Youth

Model	Linear Model D.V	Constant	Predictor	R	R^2	Std.Error of the Estimate	F	Sig.
1	VO2 max	= 46.221	+ .228 (Age)	.113	.013	4.1250	.943	.335
2	VO2 max	= 47.549	+ .050 (B.wt.)	.126	.016	4.1186	1.170	.283
3	VO2 max	=39.253	+ .067 (Height)	.133	.018	4.1145	1.319	.254
4	VO2 max	=53.222	- .039 (HRrest)	.076	.006	4.1396	.421	.518
5	VO2 max	=44.758	+ .049 (Ex.HR2Min)	.131	.017	4.1159	1.268	.264
6	VO2max	=2.831	+ .336 (Ex.HR4Min.)	.537	.289	3.5011	29.642	.000
7	VO2 max	=50.492	+ .002 (Ex.HR6Min.)	.005	.000	4.1515	.002	.967
8	VO2 max	=48.672	+ .018 (Rcv.HR1Min.)	.080	.006	4.1381	.476	.493
9	VO2 max	=49.260	+.015 (Rcv.HR2Min.)	.066	.004	4.1425	.320	.574
10	VO2 max	=49.276	+ .063 (Rcv.HR3Min.)	.063	.004	4.1432	.295	.589

Dependent Variable: VO2 max.

The model 1 (VO2 max. = 46.221 + .228 × Age) with very poor power of prediction (R2 = .013). The model 2 (VO2 max. = 47.549 + .050 × Body weight) with very poor power of prediction (R2 = .016). The model 3 (VO2 max. = 39.253 + .067 × Height) with very poor power of prediction (R2 = .018). The model 4 (VO2 max. = 53.222 - .039 ×HRrest) with very poor power of prediction (R2 = .006). The model 5 (VO2 max. = 44.758 + .049 × Ex.HR2Min) with very poor power of prediction (R2 = .017). The model 6 (VO2 max. = 2.831 + .336 × Ex.HR4Min.) with average power of prediction (R2 = .289). The model 7 (VO2 max. = 50.492 + .002 × Ex.HR6Min) with very poor power of prediction (R2 = .000). The model 8 (VO2 max. = 48.672 + .018 × RcvHR1Min.) with very poor power of prediction (R2 = .006). The model 9 (VO2 max. = 49.260 + .015 × RcvHR2Min.) with very poor power of prediction (R2 = .004) and the model 10 (VO2 max. = 49.276 + .063 × RcvHR3Min.) with poor power of prediction (R2 = .004).Hence, model 6 proved to be the best linear model.

Table-5 Estimation of VO2 Max. using Developed Linear Models for Delhi Male Youth

Case No	Actual VO2 max.	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
		VO2max. from Developed Linear Models									
07	56	51.46	51.10	51.45	50.92	50.73	**52.23**	50.83	50.72	50.67	50.70
14	55	**51.46**	49.95	50.24	51.12	50.29	49.87	50.83	50.45	50.50	50.57
21	53.5	50.32	50.65	50.51	50.72	50.49	48.86	50.82	50.85	50.86	**50.90**
28	52	50.32	**51.29**	50.97	50.96	51.17	53.23	50.85	51.01	50.98	50.73
75	41	50.55	50.44	50.44	50.53	50.49	**46.55**	50.81	50.49	50.53	50.57

According to the table-5**,** in regard to the case number07, the actual VO2 max. was 56.M1 estimated 51.46, M2 estimated 51.10, M3 estimated 51.45, M4 estimated 50.92, M5 estimated 50.73, M6 estimated 52.23, M7 estimated 50.83, M8 estimated VO2 max value of 50.72, M9 estimated 50.67 and M10 estimated VO2 max value of 50.70.

Likewise, in regard to the case number14, the actual VO2 max. was 55.M1 estimated 51.46, M2 estimated 49.95, M3 estimated 50.24, M4 estimated 51.12, M5 estimated 50.29, M6 estimated 49.87, M7 estimated 50.83, M8 estimated VO2 max value of 50.45, M9 estimated 50.50 and M10 estimated VO2 max value of 50.70.

Likewise, in regard to the case number21, the actual VO2 max. was 53.5. M1 estimated 50.32, M2 estimated 50.65, M3 estimated 50.51, M4 estimated 50.72, M5 estimated 50.49, M6 estimated 48.86, M7 estimated 50.82, M8 estimated VO2 max value of 50.85, M9 estimated 50.86 and M10 estimated VO2 max value of 50.90.

Likewise, in regard to the case number28, the actual VO2 max. was 52. M1 estimated 50.32, M2 estimated 51.29, M3 estimated 50.97, M4 estimated 50.96, M5 estimated 51.17, M6 estimated 53.23, M7 estimated 50.85, M8 estimated VO2 max value of 51.01, M9 estimated 40.98 and M10 estimated VO2 max value of 50.57.

Likewise, in regard to the case number 75, the actual VO2 max. was 41. M1 estimated 50.55, M2 estimated 50.44, M3 estimated 50.44, M4 estimated 50.53, M5 estimated 50.49, M6 estimated 46.51, M7 estimated 50.81, M8 estimated VO2 max value of 50.49, M9 estimated 50.53 and M10 estimated VO2 max value of 50.57.

The closest to actual VO2 max. value was found in model M6, 07 and 75 case, model M1 in case 14, model M10 in case 21 and model M2 in case 28 Hence model 6 was proved and documented as the best model for estimating the VO2 max. value of male youth of Delhi.

Conclusions

The developed linear models are appropriate for estimating VO2 max. for habitat of low altitude Delhi youth for aerobic fitness evaluation. Model No. 6 has been documented as most accurate model with highest power of prediction and validity hence is recommended for future research.

Conflict of Interest: No Conflict of Interest declared among authors

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