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Distribution of oxygen consumption by graded loads during ergonometric testing

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ABSTRACT

Cardiopulmonary exercise monitoring is a valuable method not only for the evaluation of medical health, but also for the assessment of patients with cardiac or pulmonary dysfunction. Spiroergometry provides additional criteria for the assessment of cardiopulmonary efficiency compared to simple ergometry. Maximal oxygen consumption (VO2max) is the most critical variable during spiroergometry. Most submaximal exercise measures provide the heart rate (HR) response to predetermined workloads in equations or nomograms used to predict VO2max. According to previous studies, the heart rate is divided into five fields. In this paper, we are doing a new redistribution of heart rates-to-workloads into seven fields, corresponding to the ergo bar. In other words, an answer is given based on the initial anthropological values of the subjects, when and in which field there will be a mismatch between the lung capacity of the subjects and the power required for that field.

Keywords: Ergonomics, biomechanics, ergonomic testing, numerical methods

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1. Introduction

Health-related fitness is the ability to perform everyday life tasks without excessive exhaustion. The components are cardio-respiratory capacity, physical strength and endurance, flexibility and body composition. Physical fitness is typically accomplished by good diet, exercise, grooming and rest. It is necessary to participate in physical activity to remain healthy [1].

Physical inactivity is increasing on a global scale, with drastic implications for the overall health of the population and a major burden on healthcare systems. Inactive individuals have higher body fat levels and are at greater risk for cardiovascular disease relative to regularly active individuals. Physical inactivity is estimated to be the world's fourth largest risk factor for mortality [2].

Bicycle and treadmill exercise tests are used in sports medicine and occupational medicine for the diagnosis of latent disease, for the evaluation of care, and for the assessment of patients ' physical strength and reservoir ability. The most popular standard methods for ergometric testing are bicycle ergometry and treadmill ergometry. Other research techniques, such as rowing ergometry, field step research, rotational ergometry, supine bicycle ergometry, stair-climbing, six-minute walking test, and strength tests, are used to assess success in sport-specific exercises and to address relevant clinical questions [3].

Cardiopulmonary exercise monitoring is a valuable method not only for the evaluation of medical health, but also for the assessment of patients with cardiac or pulmonary dysfunction. Spiroergometry provides additional criteria for the assessment of cardiopulmonary efficiency compared to simple ergometry [4].

Spiroergometry is a method for the qualitative and quantitative evaluation of cardiocirculatory, pulmonary and metabolic reactions to exercise. Measurements of oxygen intake, carbon dioxide output, minute breathing and heart rate provide important diagnostic and prognostic information in a wide range of clinical settings. Maximal oxygen consumption (VO2max) is the most critical variable during spiroergometry [5].The VO2max measures provide efficiency in the exercise of a medication due to a detailed assessment of the physical conditioning level of the person [6].VO2max represents the maximum amount of oxygen obtained, transferred and used, a commonly recognized physiological measure used to make decisions on the dosage, monitoring and assessment of physical exercise programs[7].

As age rises, VO2max continues to decrease, according to some sources, by 10% per decade [8].To the best of our knowledge, submaximal exercise experiments designed to measure VO2max or VO2peak have usually been conducted on white male and female samples, and seldom have a diverse ethnic representation. The validity and reliability of the VO2max results are undermined if the participants being tested do not reflect the pool of participants used to create the study. Most submaximal exercise measures provide the heart rate (HR) response to predetermined workloads in equations or nomograms used to predict VO2max. Differences in HR responses to submaximal exercise lead to the systematic overestimation or underestimation of VO2max when using submaximal exercise tests in ethnically diverse groups [9].

The Edwards method (Internal Load Analysis) of the 5 cardiac zones (Z1: 50-60% HRmax; Z2: 60-70% HRmax; Z3: 70-80% HRmax; Z4: 80-90% HRmax; Z5: 90-100% HRmax) allows you to test the distribution of work intensity during the entire training session and to test the percentage time at high intensity (90-95 percent HRmax) to produce different aerobic-level cardiovascular adaptations [10].

2. Aim

The aim of this study is to redistribute the existing five heart rate zones to the seven new zones. Thus, for the foregoing models, an analysis is performed and the relevant indicators are graphically displayed, and to determine for which angle and lung load the model can withstand the given load, by default anthropological values.

3. Materials

Theoretical analysis will be done for subjects modeled on the following anthropological values: model weights: 60, 70, 80, 90 and 100 kg; height: 180 cm for all models; age: 40 years old; Heart Rate: HR = 220 - 40 = 180 beats/min.

According to previous studies, the heart rate is divided into five fields (zones):

Zone Z1: healthy heart zone (50-60% of heart rate, i.e. 90-108 beats/min)
Zone Z2: moderate heart zone (60-70% of heart rate, i.e. 108-126 beats/min),
Zone Z3: aerobic heart zone (70-80% of heart rate, i.e. 126-144 beats/min),
Zone Z4: border heart or anaerobic zone (80-90% of heart rate, i.e. 144-162 beats/min),
Zone Z5: red line zone (90-100% heart rate, i.e. 162-180 beats/min).

4. Results

In this paper, these zones are expanded with the new distribution shown in Table 1, so that seven heart zones are obtained instead of five Fig. 1). The aim of the paper is to analyze and model the relevant indicators for the given models, and to determine for which angle and lung load, the model can withstand the given load, by default anthropological values.

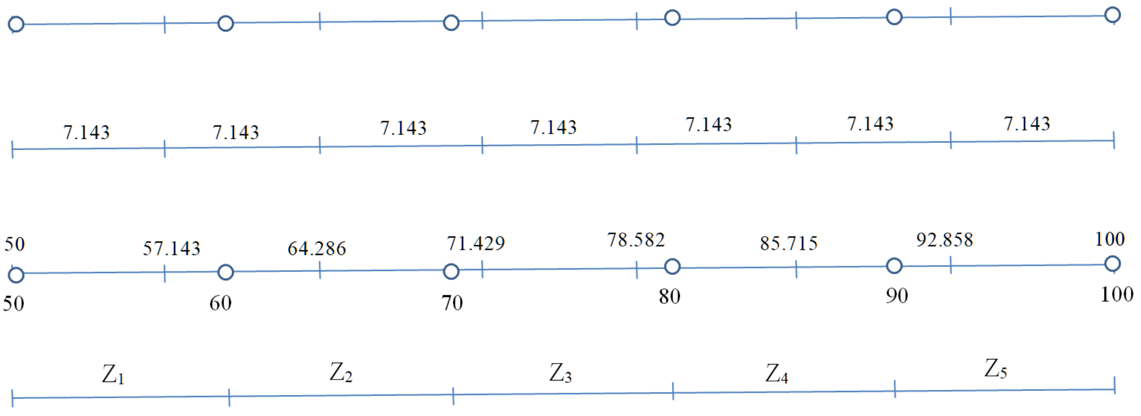

Figure 1. Heart rate distribution (five to seven zones)

Heart rate is calculated by multiplying the percentage by 180. The results are shown in Table 1. and Table 2.

4.1. Calculation by starting points and by fields

Table 1. Calculation by starting points and by fields

	%	HR [beats/min]
1.	50.00	90
2.	57.14	103
3.	64.29	116
4.	71.43	129
5.	78.57	141
6.	85.72	154
7.	92.86	167
8.	100.00	180

Field	%	Basis	HR [beats/min]
1 – 2	53,57	(90 + 103)/2	97
2 – 3	60,715	(103 + 116)/2	110
3 – 4	67,86	(116 + 129)/2	123
4 - 5	75	(129 + 141)/2	135
5 - 6	82,14	(141 + 154)/2	148
6 – 7	89,29	(154 + 167)/2	161
7 - 8	96,43	(167 + 180)/2	174

This is followed by a calculation of oxygen consumption (l/min) according to the weights of the model.

Table 2. Oxygen consumption of model weighing Q = 80 kg depending on slope and treadmill velocity

#	Model weight Q [kg]	Treadmill velocity [km/h]	Slope [%]	VO_2 average [ml/kg/min]	Q * VO_2 average [l/min]
1	80	0	0	7.0	0.560
2	80	2.70	10	15.75	1.260
3	80	4.00	12	24.25	1.940
4	80	5.50	14	35.75	2.860
5	80	6.70	16	45.75	3.660
6	80	8.0	18	55.75	4.460
7	80	8.8	20	65.75	5.260
8	80	9.6	22	74.00	5.920

Similar data were obtained for models weighing 60, 70, 90 and 100kg.

4.2. Lung capacity calculation

The analysis will be performed for different weights (60, 70, 80, 90 and 100 kg) and identical heights (h = 180cm) of the model, aged 40 years. According to Brocca [11], ideal body weight is calculated as (height in centimeters - 100 = 80kg).

The maximum heart rate is determined by the form SF = 220 - 40 = 180, while the anaerobic zone was calculated as

HR = 180 x 0.85 = 153 beats/min.

We now calculate the power required for our optimal subject weighing 80 kg and having a height of 180 cm. We take into account that there are seven fields on the treadmill with different lengths, different slopes and different speeds, as shown in Table 3.

Table 3. Calculation of the vertical climb

length [m]	slope [%]	angle	vertical climb [m]
135	10	5,75	13.40
200	12	6.84	23.80

275	14	7.76	37.12
375	16	9.09	59.25
400	18	10.20	70.80
440	20	11.30	85.80
480	22	12.40	102.70

The power calculations per field (W [kgm^2/s^2]) give

W1 = 80x179.6/10800.= 1.33

W2 = 80x566.4/10800= 4.19

W3 = 80x1377.89/10800= 10.20

W4 = 80x 351056/10800 = 26.60

W5 = 80x5012.64/10800=37,13

W6 = 80x7361.64/10800= 54.53

W7 = 80x10547.29/10800= 78.13

Finally, the total power is

W = 1.33+4.19+10.2+26.604+37.13+54.53+78.13 = 211.5 [kgm^2/s^2]

From the book on page 150 Table 27. Values for Men (according to Astrand and Rhyming, modified by Živanić, 1999) [12]. In the table above we have values for W (50, 100, 150, 200 and 250). As it can be seen HR= 153 beats is in the anaerobic or border zone.

Power consumption is between 200W and 250W, more precisely 211.5 [W]

At HR = 153 and 200W power, the oxygen consumption in the table above is 4.06 [l]

At HR = 153 and a power of 250W the air consumption from the table above is 5.13 [l]

5.13-4.06 = 1.07 The difference between 200 and 250 is 50

1.07: 50 = 0.0214; 211.5-200 = 11.5; 0.0214x11.5 = 0.246

Therefore, for a power of 211.5 W it takes VO2max = 4.06 + 0.246 = 4.31 [l]

With the calculation we got VO2max = 4.31 [l], while experimentally VO2max = 4.35 [l] which is 99% match.The values calculated above coincide with the experimentally determined values shown in [12].

Table 4. Oxygen consumption depending on slope and treadmill velocity

Weight[kg]	Treadmill velocity[m/min] (*x-axis*)							
	0.00	2.70	4.00	5.50	6.70	8.00	8.80	9.60
	Oxygen consumption[l/min] (*y-axis*)							
60	0.42	0.95	1.55	2.15	2.75	3.35	3.95	4.44
70	0.49	1.10	1.80	2.50	3.20	3.90	4.61	5.18
80	0.56	1.26	2.06	2.86	3.50	4.46	5.26	5.90
90	0.63	1.42	2.32	3.22	4.12	5.02	5.92	6.66
100	0.70	1.58	2.58	3.58	4.58	5.58	6.58	7.40

Oxygen consumption values of the arithmetic means of the minimum and maximum intervals for each of the seven fields are shown in Table 4.

Based on the data in Table 4, a graphical representation was created for each individual weight of the subjects. After graphing, regression analysis was performed using a second-order polynomial (quadratic interpolation).

Regression analysis determined the regression coefficients, whose values are shown in Table 5. R^2 for all approximation was well above 0.99.

4.3. Model weighing of 80 kg

The exceeded load the standard model is at the end of the IV field and starts at a critical lane speed of 6.74 [km/h] (point B), while for the sports model it is near the end of the V field and starts at the critical treadmill velocity of 7.73 [km/h] (point A) (Figure 2.)

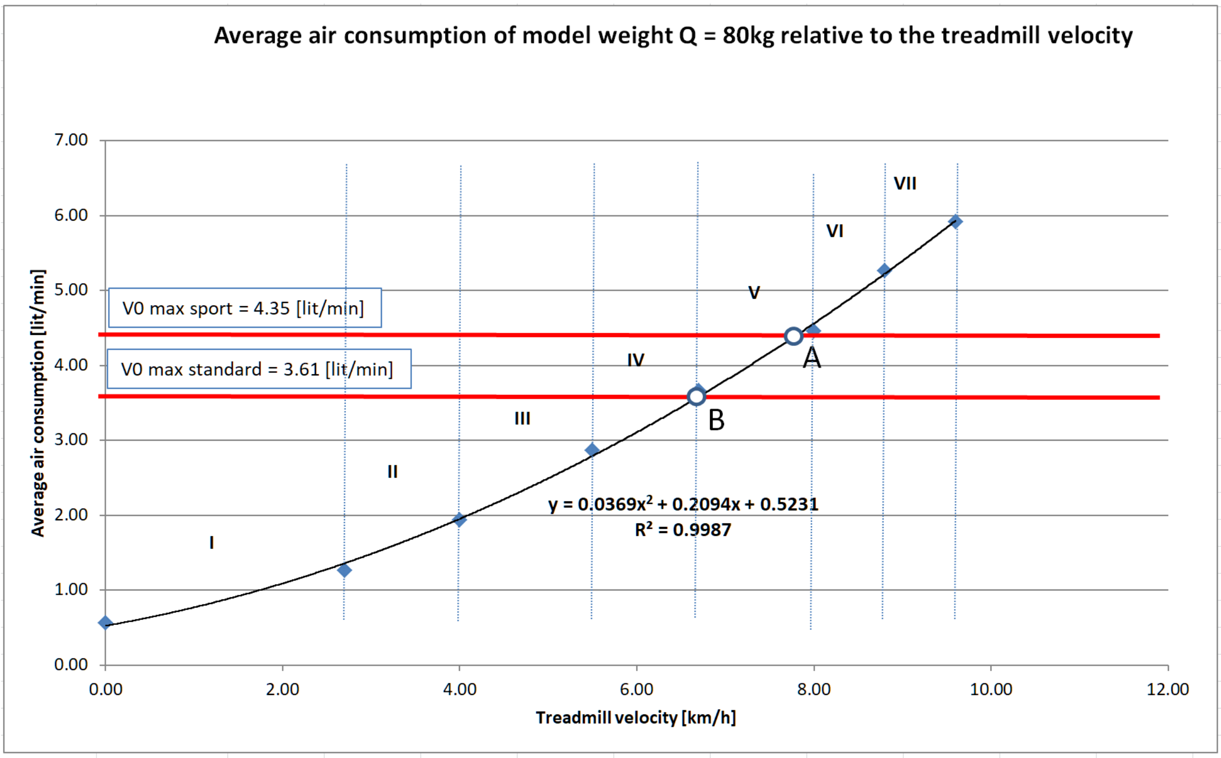

Figure 2. Average oxygen consumption of model weighing Q = 80kg depending on the slope and treadmill velocity with respect to the allowed load of lung capacity

Similar graphs were obtained for models weighing 60, 70, 90 and 100kg.

The regression analysis is determined by the quadratic polynomial of the form:

$$y = ax^2 + bx + c$$

where the regression coefficients a, b, c are shown in Table 5 for the weight values of 60, 70, 80, 90 and 100 kg.

The intersection points A and B were obtained by analytical solution of the above equation for the value y = 4,35 [l/min] (sporting model) and 3.61 [l/min] (standard model).

The values for the intersection points A and B are given in Table 5.

4.4. Allowed lung load relative to model weight and load fields

Table 5. Regression coefficients and critical treadmill velocity for the sport and standard model

Model weight [kg]	Regression coefficients			Intersection point **A**	Intersection point **B**
	a	b	Treadmill velocity [km/h]	Treadmill velocity [km/h]	Treadmill velocity [km/h]
60	0.0277	0.1571	0.3923	9.45	8.31
70	0.0323	0.1830	0.4577	8.50	7.44
80	0.0369	0.2094	0.5231	7.73	6.74
90	0.415	0.2354	0.5885	7.10	6.16
100	0.0461	0.2618	0.6539	6.55	5.67

The critical treadmill velocity for all weights are shown graphically in Figure 3. A regression analysis with a very high R^2 ($R^2 = 0.9998$ and $R^2 = 0.9999$) was performed.

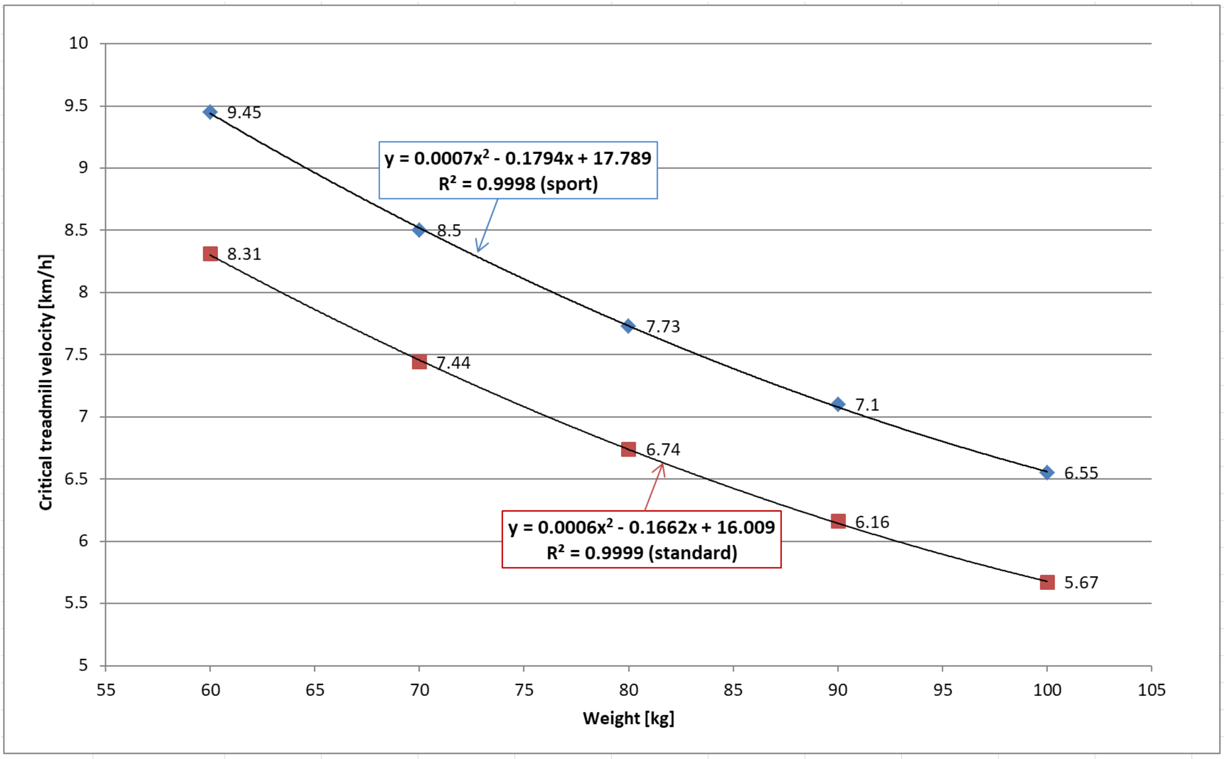

Figure 3. Critical treadmill velocity for sport and standard model weights of 60, 70, 80, 90 and 100 [kg]

5. Conclusions

For all weights from 60 to 100 kg, the specified regression function can be used to determine the oxygen consumption when, in what field, and at which speed a disproportion between the oxygen consumption and the power that the subject needs to master on the treadmill will occur.

6. References

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