Maximum Ventilatory Equivalents and Oxygen Pulse in the Pre-competitive Phase of Military Athletes. An Observational Study

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Abstract

The ventilatory equivalents for oxygen (VE/VO_2), carbon dioxide (VE/VCO_2), and oxygen pulse ($PulO_2$) influence exercise response. **Objective.** To analyze the precompetition ventilatory equivalents and maximum oxygen pulse in a group of military athletes. **Methodological design.** A retrospective research assessing $PulO_2$, VE/VO_2, and VE/VCO_2 in relation to other physiological variables through ergoespirometry. Descriptive statistics were applied. Levene's test was used to assess variance homogeneity. Data distribution was verified by using the Shapiro-Wilk test. The Kruskal-Wallis H test, Student's t test, and Pearson's coefficient were also applied. **Results.** Sixty athletes aged 21 ±2 years, 80% (n = 48) men and 20% (n = 12) women, participated in the study. The ventilatory equivalents showed no differences by gender ($p > 0.05$). However, they did differ by type of sport (p 0.02). The $PulO_{2max}$ showed differences by gender and type of sport ($p > 0.01$). The VE/VCO_{2max} and the VO_{2max} were related with the test duration, and the $PulO_{2max}$ with speed. **Conclusions.** The VE/VCO_{2max} and $PulO_{2max}$

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should be part of the military physical training, given the differences by gender and type of sport.

Keywords: ergoespirometry; oxygen pulse; sports; VE/$VCO_{2max;}$ ventilatory equivalents

Introduction

Cardiopulmonary exercise testing (CPET), or ergospirometry, is a diagnostic procedure to assess the function and capacity of the cardiovascular, pulmonary, and metabolic systems. It provides information on the body's response to dynamic stress and is routinely used in stress testing laboratories (1), monitoring and evaluating respiratory functions, and gas analysis during physical activity and, at the same time, cardiac function under load. The CPET is a diagnostic and prognostic tool, useful in assessing the cause of shortness of breath (dyspnea) and providing a prognostic assessment of patients with cardiovascular and pulmonary diseases, such as coronary disease, chronic obstructive pulmonary disease (COPD), pulmonary embolism, and hyperventilation syndrome, as well as exercise-induced asthma, among others (2) (3).

This non-invasive and objective method provides a very accurate assessment of the function of the cardiovascular, pulmonary, muscular, and metabolic systems during exercise in quantified manner. It is commonly calculated based on the treadmill or cycloergometer's working speed and is considered the gold standard for cardiopulmonary functional assessment. Therefore, many medical specialties, like cardiology, pneumology, and sports medicine or sports science, have benefited from this test (4) (5) (6) (7).

The CPET is an important method in functional evaluation in Colombia and globally. Its most frequent uses involve applying an intensity exercise that gradually increases until exhaustion or until limiting symptoms or signs occur (8). The test is based on measuring exhaled gases during exercise. Among other things, it estimates pulmonary ventilation (PV), oxygen consumption (VO_2), carbon dioxide production (VCO_2), VO_2 maximum (VO_{2max}), VCO_2 maximum (VCO_{2max}), and the ventilatory equivalents for oxygen (VE/VO_2) and carbon dioxide (VE/VCO_2). In some special situations, it measures pulse saturation both during and after exertion (9) (10).

Oxygen consumption (VO_2) is defined as the volume of oxygen (O_2) extracted from the air inhaled during pulmonary ventilation (PV) over a time span. In practice, the maximum VO_2 (VO_{2max}) is the highest value achieved, despite the progressive increase in the applied load (4). It is calculated from the difference between the volume of O_2 in the inhaled and exhaled air during exercise per time unit. The VO_2 is determined by the cellular O_2 demand. In healthy people, it increases linearly as external work increases (11).

Carbon dioxide (VCO_2) production is the difference between the volume of CO_2 in the air inhaled and exhaled during exercise per unit of time and represents the metabolic production of carbon dioxide. This VCO_2 is affected by the same factors as VO_2; however, it is more dependent on ventilation because of the greater solubility of CO_2 in the blood.

Several variables in CPET, including the respiratory quotient (RER) and ventilatory equivalents, are derived from VCO_2 (12). The RER expresses the relationship between CO_2 production and O_2 consumption (VCO_2/VO_2). It is currently the best non-invasive indicator of maximum or near-maximum exercise intensity. Values >1.0 may reflect intense exercise. However, in a CPET, those ≥ 1.10 are sought (2) and have been accepted as a parameter of exhaustion or near-exhaustion (13). Lactic acid production nearing exhaustion results in an RER > 1 because additional CO_2 is introduced into the system from a bicarbonate buffering (HCO_3). Thus, an RER substantially > 1 in maximum exercise is a maximum effort marker. Hyperventilation can also cause an RER >1 (12). Some authors maintain that a person has reached maximum testing when they reach at least two of the following criteria: reaching and maintaining the VO_{2max} plateau, even if the workload increases, to reach the maximum predicted heart rate and reaching an RER ≥ 1.15 (14). Figure 1 shows the expected behavior of VO_2 and VCO_2, rising linearly, with VO_2 greater than VCO_2 until the VO_2 plateau is reached.

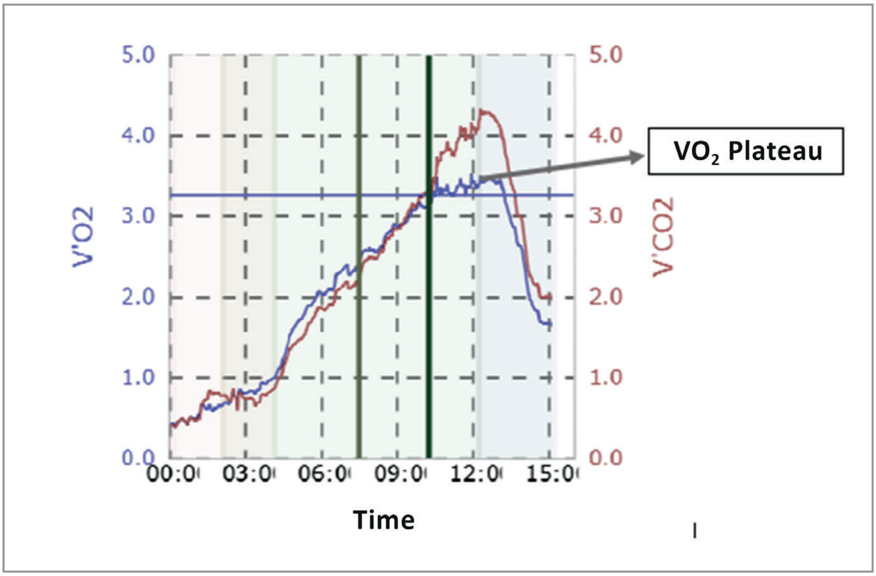

Figure 1. VO_2 and VCO_2 behavior
Source: Research data

Pulmonary ventilation (PV) is expressed in liters per minute and represents the air volume entering and leaving the lungs. It is defined as the product of the breathing frequency (BF) by the current volume exhaled in each cycle depending on: 1) the process of cellular respiration, 2) interaction between sensors and receptors that capture physical or chemical changes, 3) the central control that triggers the frequency and depth of each breath, sending stimuli to the respiratory muscles, and 4) the mechanical effectors that facilitate inhalation and exhalation. In this sense, sensors located in the central nervous system (CNS) capture changes in pH and central temperature. Outside the CNS, there are carotid and aortic bodies that are sensitive to changes in $PaCO_2$, PaO_2, and pH. Some receptors located in the upper airway (nose, pharynx, and larynx) and the lung receptors (stretch receptors, irritation receptors, and juxtacapillary receptors) are also involved. Finally, the respiratory muscles' (neuromuscular and Golgi tendon organ uses) receptors also modulate ventilation by conditioning the muscles' level of stretching and shortening. Regarding central control, the pneumotaxic center located in the pons is responsible for inhibiting inspiration and increasing the respiratory rate. The apneustic center does the opposite, increasing inspiratory time. The bulbar centers are in charge of stimulating the respiratory muscles (15).

At rest, 7 to 9 L/min of air are ventilated; however, in athletes, this value can reach 200 L/min with maximum effort (16) (7). Ventilation increases continuously during progressive stress in CPET and undergoes additional increases influenced by anaerobic metabolism resulting from the accumulation of lactic acid, defined as the first and second ventilation thresholds (17).

MOreover, the oxygen pulse (pulse of O_2) is the ratio of VO_2 to heart rate (HR) and is expressed in ml/beat (18). Low oxygen pulse during exercise may indicate decreased systolic volume or an abnormality in the extraction of oxygen from the skeletal muscle. Low HR during exercise, caused by Beta-blocker medications, may raise the O_2 pulse by lowering the denominator (18).

The VE/VO_2 and VE/VCO_2 are indicators of respiratory efficiency. They are defined as the relationship between pulmonary ventilation and oxygen consumption (VE/VO_2) or between pulmonary ventilation and carbon dioxide production (VE/VCO_2) during an incremental exercise test (7) (19). Both decrease from rest to sub-maximal exercise intensities, reaching minimum values before the anaerobic threshold (AT), when there is a progressive increase caused by increased ventilation to eliminate the additional production of CO_2, which results in a bicarbonate-in-blood lactate buffer (6). Figure 2 shows a graphic example of the behavior of the VE/VO_2 and the VE/VCO_2 in which a gradual increase in the former and a progressive decrease in the latter can be observed.

In different types of sports training, the CPET is a useful and valuable test to evaluate athletes and monitor their progress. Like athletes, military personnel must also have good physical condition to perform optimally to meet operational requirements in stressful and rigorous environments and life-threatening conditions associated with their work (20). The Armed Forces have historically invested in preparing elite and Olympic-level athletes

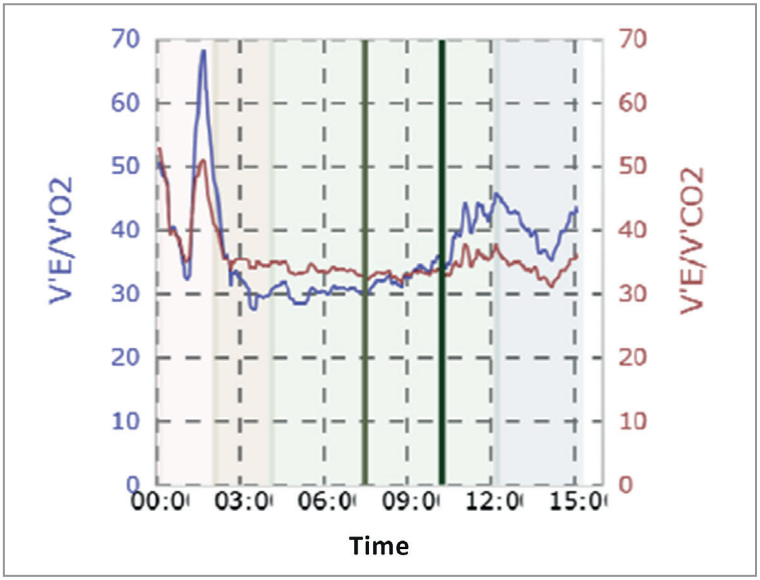

Figure 2. Behavior of VE/VO_2 and VE/VCO_2
Source: Research data

worldwide (21). There is little evidence of studies involving the military athlete population and, to our knowledge, this is the only study that focuses primarily on this analysis in Colombia. Therefore, this study's objective was to analyze the ventilatory equivalents and the maximum oxygen pulse of a group of military athletes in the pre-competitive phase.

Methods

This retrospective, observational study analyzed 76 ergospirometry tests conducted with military athletes in the 2018 pre-competitive phase of different disciplines, including sprints, long-distance running, orienteering, triathlon, pentathlon, and soccer and basketball. Only 60 maximum tests were considered (respiratory quotient ≥ 1.10) (22). The subjects were evaluated in the Research Center of Physical Culture (CICFI in Spanish) at *Escuela Militar de Cadetes "General José María Córdova"* (ESMIC). Testing was performed by using an HP Cosmos treadmill with a Metalyzer 3B-R2 spiroergometry device, at 22.6 °C and barometric pressure of 560 mmHg. All of them followed an aerobic power protocol, starting with a 4-minute warm-up at 4 km/h. The initial treadmill's speed was 7 km/h; it increased by mile, every minute, until exhaustion, with a constant inclination of 1%. Ventilation (VE), carbon dioxide production (VCO_2), maximum ventilatory equivalent for oxygen and carbon dioxide, maximal oxygen pulse (VO_{2max}/HR_{max}), respiratory quotient (VCO_2/VO_2), maximum breathing rate (BR_{max}), maximum current volume (VC_{max}), and oxygen consumption (VO_{2max}) were considered ventilatory variables. Maximum heart rate (HR_{max}) was analyzed among the cardiac variables.

The data were aggregated into an Excel matrix for further analysis by using the SPSS v. 21 statistical package. Use of the data was approved by the military school's ethics committee.

Results

Sixty subjects were analyzed retrospectively; 80% (n = 48) were men and 20% (n = 12) women. The mean age was 21 ± 2 years, weight was 68 ± 10 kg, height was 1.71 ± 10 m., and BMI was 23.1 ± 1.8 kg/m^2. Body surface area was 1.8 ± 0.18 m^2, HR_{max} was 1.84 ± 9 L/min. Furthermore, VO_{2max} was 45.6 ± 6.6 ml/kg/min., VO_{2max} was 3.11 ± 0.63 L, VCO_{2max} was 3.6 ± 0.7 L, VE_{max} was 148.2 ± 27 L, VE/VO_{2max} was 52.6 ± 10.2 **(unit of measure?)**, VE/VCO_{2max} was 41.17 ± 4.6 **(unit of measure?)**, RF_{max} was 68.9 ± 10 r/min, VC_{max} was 2.1 ± 0.48 L. Oxygen pulse was 17 ± 3.5 ml/heartbeat, and the respiratory quotient was 1.2 ± 0.10 **(unit of measure?)**. Ten percent (n = 6) of the population practiced pentathlon, 22% (n = 13) soccer, 12% (n = 7) long-distance running, 20% (n = 12) orienteering, 8% (n = 5) triathlon, 16% (n = 10) sprints, and 12% (n = 7) basketball. The differences by gender are presented in **Table 1** and the differences by type of sport are presented in **Table 2**.

Table 1. Behavior of cardiopulmonary variables by gender

Variable	Median and SD		*P*
	Men	Women	
Age (years)	20.7 ± 1.7	20 ± 1.9	*2.01*
Weight (kg)	71.19 ± 8.5	56.07 ± 6.4	*0.00*
Height (m)	1.74 ± 0.08	1.58 ± 0.05	*0.00*
BMI (kg/m^2)	23.37 ± 1.85	22.24 ± 1.58	*0.05*
Test duration (minutes)	15.39 ± 2.96	14.28 ± 3.14	*0.25*
Body surface area (m^2)	1.85 ± 0.15	1.57 ± 0.12	*0.00*
Speed (km/h)	18.83 ± 1.63	15.66 ± 1.06	*0.00*
HR Rest (BPM)	79 ± 10	83 ± 8	*0.14*
HR_{max} (BPM)	183.5 ± 8	186.8 ± 12	*0.26*
VO_{2max} (L)	3.34 ± 0.48	2.21 ± 0.26	*0.00*
VO_{2max} (ml/kg/min)	47.16 ± 6.15	39.66 ± 4.9	*0.00*
VCO_{2max} (L/min)	3.89 ± 0.48	2.56 ± 0.32	*0.00*
VE_{max} (L/min)	157.53 ± 20.33	111.3±17.98	*0.00*
VE/VO_{2max}	51.32 ± 10	57.90 ± 9.85	*0.45*
VE/VCO_{2max}	40.62 ± 4.52	43.36 ± 4.58	*0.66*
BR_{max} (rpm)	70.22 ± 9.94	64 ± 9.34	*0.05*
VE_{max} (L/min)	2.27 ± 0.36	1.75 ± 0.27	*0.00*
O_2 pulse (ml/beat)	18.25 ± 2.77	12.08 ± 1.44	*0.00*
Respiratory Quotient	1.20 ± 0.11	1.16 ± 0.1	*0.23*

* Significance level ($p < 0.05$).
Source: Created by the authors from research data.

Table 2. Behavior of cardiopulmonary variables by type of sport

Variable	Median and SD		P
	Individual	Group	
Age (years)	21±2	21±1	*0.54*
Weight (kg)	64.9±8.4	74.6±10.4	*0*
Height (m)	1.70±0.1	1.80±0.1	*0.01*
BMI (kg/m^2)	23.0±1.9	23.4±1.7	*0.43*
Test duration (minutes)	15.9±3.3	13.8±1.5	*0.11*
Body surface area (m^2)	1.7±0.2	1.9±0.2	*0*
Speed (km/h)	18.3±2.3	18.1±1.4	*0.74*
HR Rest (BPM)	80.5±10.8	78.9±9.7	*0.57*
HR_{max} (BPM)	186.6±9.2	179.4±7.5	*0.03*
VO_{2max} (L)	3.0±0.7	3.3±0.5	*0.18*
VO_{2max} (ml/kg/min)	46.6±7.5	43.9±3.9	*0.13*
VCO_{2max} (L/min)	3.4±0.7	4±0.6	*0.01*
VE_{max} (L/min)	144.7±28.3	155.4±23.9	*0.15*
VE/VO_{2max}	55.5±8.5	47±11.3	*0.02*
VE/VCO_{2max}	42.4±4.6	38.4±3.6	*0.02*
BR_{max} (rpm)	70.9±11.1	65.1±6	*0.03*
VE_{max} (L/min)	2.1±0.4	2.4±0.4	*0.01*
O_2 pulse (ml/beat)	16.4±3.7	18.4±3	*0.03*
Respiratory Quotient	1.18±0.1	1.2±0.1	*0.04*

Source: Created by the authors from research data

The VE/VO_{2max} and VE/VCO_{2max} showed no significant differences by gender. However, differences were found by type of sport. For individual sports, the VE/VO_{2max} was 55.5 ± 8.5 and 47 ± 11.3 in team sports; VE/VCO_{2max} was 42.4 ± 4.6 and 38.4 ± 3.6, respectively, p = 0.00 in both cases.

The $PulO_{2max}$ showed differences by gender. It was 18.25 ± 2.77 ml/beat for men and 12.08 ± 1.44 ml/beat for women, with p =0.00. For individual sports, it was 16.4 ± 3.7 ml/beat and 18.4 ± 3 ml/beat for team sports, with p = 0.01. The VE/VCO_{2max}, was related to the VE/VO_{2max} (r = 549, p = 0.00), with the VO_{2max} (0.342 ± 0.00), with the test duration (r = 0.385, p = 0.00). In turn, test duration was related with the VO_{2max} (r = 0.518, p = 0.00). The VE/VO_{2max} was related with weight (r = -373, p = 0.00), with the body mass index (r = -317, p = 0.00), and with the VCO_{2max} (r = -317, p = 0.00). The $PulO_{2max}$ was related with length (r = 0.693, p=0.00), weight (r = 732, p=0.00), BMI (r = 335, p = 0.00), speed (r = 414, p = 0.00), VCO_{2max} (r = 0.781, p=0.00), with the VE_{max} (r = 0.828, p = 0.00), and with the VO_{2max} (r = 0.661, p = 0.00). The VO_{2max} was related with the RF_{max}. (r = 0.474, p = 0.00).

Discussion

This study's main objective was to evaluate the athletes' physical and functional conditions in the pre-competitive phase to implement training plans to optimize performance during competition. It was evidenced that the maximum ventilatory equivalent for carbon dioxide, maximum oxygen consumption, and oxygen pulse showed a significant impact on the duration of the test and, therefore, on the performance of the athletes evaluated.

Herdy and Uhlendorf established VO_{2max} scales in 2,388 Brazilian men and 1,534 women. The subjects included healthy, sedentary, and physically active individuals. The authors reported average values in the active population of 50.6 ± 7.3 ml/kg/min for men and 38.9 ± 5.7 ml/kg/min for women (4). In our study, slightly higher values were found in women and lower in men. These differences could be due to the type of population, race, and age. The comparison of our results with Herdy and Uhlendorf's study corresponds to their 15 to 24-year-old group, given that our study's minimum age was 18.

It has been reported that *VE*/VCO_2 is unrelated with the athlete's ability to use oxygen or achieve high performance (23). However, in this study, a positive correlation was found between this variable and the test duration in the pre-competitive phase. Therefore, it is recommended to monitor it during training, as suggested by Sauer, Pérez, and Cartelli (24). It should be noted that these authors reported weak correlations between *VE*/VCO_2 and VO_2, based on previous studies. Conversely, in this work, a statistically significant moderate correlation was found between both variables, suggesting an association between ventilation and performance. Here, it must be indicated that the subject can intake oxygen and eliminate carbon dioxide through ventilation and that according to the hemoglobin dissociation curve's behavior, decreased plasma pH, increased $PaCO_2$ or temperature, among others, cause decreased hemoglobin affinity for oxygen, favoring its delivery to tissues (25). This fact could explain the relationship found in the athletes assessed at the maximum phase.

In the same sense, a work by Nalbandiano *et al.* (26), which also considered test duration as a performance indicator, documented that breathing rate influenced neither VO_{2max} nor resistance in a group of 10 male athletes. In this work, however, a significant relationship was found between VO_{2max} and BR_{max}. Although no relationship was found between BR and test duration, it could be considered that if BR is related with VO_{2max}, it could also be related with performance. This aspect could be addressed in future studies. In this case, the breathing rate's exaggerated increase, in the maximum phase, causes a reduction in the tidal volume and an increase in $PaCO_2$, generating, as described by Minas from physiology, enhancement of the Bohr effect, optimizing O_2 delivery (27) (28). This situation would also explain the relationship found between VE/VO_2 and VCO_2.

Considering that VO_2 partially depends on the correct diffusion of gases, influenced by time constants (29), and that the HR reaches maximum levels that shorten the red blood cell's exposure time in the hematogaseous membrane during intense activities of high metabolic demand, it is possible to explain that the maximum frequencies reached by the athletes could reduce the VO_{2max}, in comparison to values found in other athletes of the same age, in the pre-competitive phase (28). Here, it is important to note that, in our study, not all athletes belonged to the same discipline and that there was no data to establish how long they had been in it. Therefore, it is recommended that future studies take these aspects into account.

Finally, Padilla's work with Mexican endurance athletes reported a positive relationship between $PulO_{2max}$ and absolute VO_{2max}. However, it also reported a negative relationship between $PulO_{2max}$ and HR_{max} (18). These findings are similar to those found in this work and corroborate that oxygen pulse complements the cardiorespiratory evaluation, as concluded by Padilla himself.

Conclusions

The ventilatory equivalent for maximum carbon dioxide (VE/VCO_{2max}) influences upon test duration, thus, breathing technique and respiratory muscle training may influence sports performance.

The $PulO_{2max}$ allows identifying cardiopulmonary resistance and, therefore, sport performance; this was reflected in its direct relation with the speed of the athletes evaluated. Therefore, training should aim to enhance $PulO_{2max}$, and strengthen ventilation, differentiating by gender and type of sport.

Acknowledgments

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References

1. CID-Juárez S, Miguel.Reyes JL, Cortés-Téllez A, Gochicoa-Rangel L, Mora-Romero UdJ, Silva-Cerón M, et al. Prueba Cardiopulmonar de ejercicio. Recomendaciones y procedimientosde ejercicio. Neumol-Cir. torax. 2015 July; 7(3): p. 207-221.
2. Thomas A, Burdiat G. Pruebas de esfuerzo cardiopulmonar. Rev.Urug.Cardiol. 2010 June; 25(1): p. 17-27.
3. Balady GJ, Arena R, Sistsema K, Myers J, Coke L, Fletcher GF, et al. Clinician's guide to cardiopulmonary exercise testing in adults: a scientific statement from the American Heart Association. Circulation. 2010 July; 122(2): p. 191-225.
4. Herdy AH, Unhlendorf D. Valores de referencias para la prueba cardiopulmonar para hombres y mujeres sedentarios y activos. Archivos brasileños de Cardiología. 2011 November; 96(1): p. 54-59.
5. Gibbons RJ, Balady GJ, Buasley JW, Bricker JT, Duvernoy WJ, Froelicher VF, et al. ACC/AHA guidelines for exercise testing: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. J Am Coll Cardiol. 1997 July; 30(1): p. 260-311.
6. Guazzi M, Adams V, Conraads V, Halle M, Mezzani A, Vanhees L, et al. European Association for Cardiovascular Prevention & Rehabilitation; American Heart Association. EACPR/AHA Scientific Statement Clinical recommendations for cardiopulmonary exercise testing data assessment in specific patient populations. Circulation. 2012 October; 126(18): p. 2261-2274.
7. Herdy AH, Fonteles Ritt E, Stein R, Gil Soares de Araujo C, Milani M, Meneghelo RS, et al. Cardiopulmonary exercise test: Backgruond, Applicability and interpretation. Arq Bras Cardiol. 2016 November; 107(5): p. 467-481.
8. Takashi AD, Flavia B, Rocha ML, Kaminura MA, Mello MT, Tufik S, et al. Impacto del entrenamiento en el umbral ventilatorio sobre la capacidad cardiopulmonar y funcional en pacientes con sobrepeso con enfermedad renal crónica. J. Bras.Nefrol. 2012 June; 34(2): p. 139-147.
9. Arena R, Myers J, Guazzi M. The clinical and research applications of aerobic capacity and ventilatory efficiency in heart failure: an evidence-based review. heart Fail Rev. 2008 June; 13(2): p. 245-269.
10. Arena R, Lavie CJ, Milani RV, Myers J, Guazzi M. Cardiopulmonary exercise testing in patients with pulmonary arterial hypertension: an evidence-based review. J Heart Lung Trnasplant. 2010 February; 29(2): p. 159-173.

11. López Chicharro J, López Mojarrez LM. Fisiología Clínica del ejercicio McArdle WD, Katch FI, Katch VL, editors. España: McGraw-Hill/Interamericana; 2004.
12. Debapriya Datta EN, ZuWallack R. Cardiopulmonary exercise testing in the assessment of exertional dyspnea. Ann Thorac Med. 2015 June; 10(2): p. 77-86.
13. Monteiro de Almeida AE, de Moraes Stefani C, do Nascimento A, de Lameida NM, da Cruz Santos A, Pinto Ribeiro J, et al. An Equation for the prediction of oxygen consumption in a a brazilian population. Arquivos Brasileiros de Cardiologia. 2014 October; 103(4): p. 299-307.
14. Hall-López JA, Ochoa-Martínez PY, Moncada-Jimenez J, Ocampo Méndez MA, Martínez García I, Martínez García MA. Confiabilidad del consumo máximo de oxigeno evaluado en pruebas de esfuerzo. Nutrición Hospitalaria. 2015; 31(4): p. 1726-1732.
15. García Cabrera L, Rodríguez Reyes O, Rodríguez Carballosa OB. Regulación de la respiración: organización morfofuncional de su sistema de control. Medisan. 2011 Apr; 15(4): p. 558-567.
16. Wasserman K, Whipp BJ. Exercise physiology in health and disease. AM Rev Resp Dis. 1975 November; 112(2): p. 219-249.
17. Corrá U, Giordano A, Bosimini E, Mezzani A, Piopoli M, JS Abrigos A, et al. Oscillatory ventilation during exercise in patients with chronic heart failure: clinical correlates and prognostic implications. Chest Journal. 2002 May; 121(5): p. 1572-1580.
18. Padilla Pérez J. Pulso de oxígeno y su cinética de la fase dos transitoria durante una prueba de esfuerzo máximo de VO2 en adultos mayores. RevHosp Jua Mex. 2011; 78(1): p. 6-11.
19. Arena R, Myers J, Hsu L, Peberdy MA, Pinkstaff S, Bensimhom D. The minute ventilation/carbon dioxide production slope is prognostically superior to the oxygen uptake efficiency slope. J Card Fail. 2007; 13(6): p. 462-469.
20. JoEllen M S, Burkhardt TA. Introduction to the Tactical Athlete Special Issue. Introduction to the Tactical Athlete Special Issue. J Athl Train. 2016 November; 51(11): p. 845-845.
21. Xavier R, Sánchez C, Paulucio D, Moreira da Silva I, Velasque R, Noriega FS, et al. A Multidimensional Approach to Assessing Anthropometric and Aerobic Fitness Profiles of Elite Brazilian Endurance Athletes and Military Personnel. Mil Med. 2019 April; 0(00): p. 1-7.
22. Niño Hernández CA. Evaluación de la aptitud cardio respiratoria. mov. Cient. 2010; 4(1): p. 68-72.
23. Salazar-Martínez E, Rodrigues de Matos T, Arrans P, Santalla A, Naranjo Orellana J. Ventilatory efficiency response is unaffected by fitness level, ergometer type, age,or body mass index in male athletes. Biology of Sport. 2018; 35(4): p. 393-398.
24. Sauer D, Perez A, Cartelli L. Efeito do treinamento sobre a eficiência ventilatória de indivíduos saudáveis. Rev Bras Med Esporte. Rev Bras Med Esporte. 2014 May; 20(6): p. 470-473.

25. Gutierrez Muñoz FR. Insuficiencia respiratoria aguda. Acta méd. peruana. 2010 December; 27(4): p. 286-297.

26. Nalbandiano M, Radak Z, Taniguchi J. How different respiratory patterns affect cardiorespiratory variables and performance. Int J Excerc Sci. 2017; 10(3): p. 322-329.

27. Patel AK, Cooper JS. Physiology, Bohr Effect. In StatPearls Internet. Treasure Island: StatPearls Publishing; 2019.

28. Di Paco A, Dubé BP, Laveneziana P.. Changes in Ventilatory Response to Exercise in Trained Athletes: Respiratory Physiological Benefits Beyond Cardiovascular Performance. Arch Bronconeumol. 2017; 53(5): p. 237-244.

29. Méndez J E, Zeledon S S, Zamora L F, Cortés V A. Un acercamiento a la cinética del oxígeno. Rev. coatarric. cardiol. 2004 May; 6(2): p. 37-42.