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**ABSTRACT**

A pulmonary function ratio describing oxygen extraction from alveolar ventilation was used for an intergroup comparison between three groups of athletes (rugby, basketball, and football players) and one group of sedentary subjects during steady-state submaximal exercise. The ratio and its component parts are determined from only three gas fractions: (a) alveolar carbon dioxide, (b) expired carbon dioxide, and (c) expired oxygen. Exercise was conducted on a bicycle ergometer at a power load of 900 kpm/min, and an open circuit method, adapted for the determination of end-tidal carbon dioxide, was used for gas analysis. Significant differences (.025 level) were found between each of the three athletic groups and the sedentary group, but no differences were found between the athletic groups. Athletes had a higher pulmonary function ratio, a higher oxygen extraction, and a lower alveolar ventilation than the sedentary subjects. (Author/JS)

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ATHLETES AND SEDENTARY INDIVIDUALS: AN INTERGROUP  
COMPARISON UTILIZING A PULMONARY FUNCTION  
RATIO OBTAINED DURING SUBMAXIMAL EXERCISE

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It was the purpose of this study to assess whether a pulmonary function ratio and its component parts, obtained during submaximal steady-state exercise, were differentiating factors when comparisons were made between sedentary subjects and athletes and between different athletic groups.

The pulmonary function ratio ( $V_{O_2}/V_A$ ) describes oxygen extraction (OEF) from alveolar ventilation (AVF) or in other words describes the ability of the pulmonary system to extract  $O_2$  from the ventilated and perfused areas of the lungs. The basic equation for this ratio is:

$$V_{O_2}/V_A = [0.265(1 - F_{E}CO_2 - F_{E}O_2) - F_{E}O_2] / (F_{E}XO_2/F_A CO_2)^*$$

The numerator in the equation is a factor (OEF) by which  $V_E$  must be multiplied in order to obtain  $V_{O_2}$ , and the denominator is a factor (AVF) by which  $V_E$  must be multiplied in order to obtain  $V_A$ . Hence,

$$V_{O_2} = V_E \times OEF \text{ and}$$

$$V_A = V_E \times AVF. \text{ Therefore,}$$

$$V_{O_2} / V_A = OEF/AVF.$$

As can be seen from the basic equation, the ratio is determined by knowledge of only the three gas fractions: alveolar  $CO_2$ , expired  $CO_2$ , and expired  $O_2$ .

It should be noted that for the purpose of this study and end-tidal  $CO_2$  is taken to represent the alveolar  $CO_2$  fraction.

\*See appendix for detailed derivation of the equation.

Subjects were obtained from four groups. They were Varsity basketball players (7), Varsity football players (10), Rugby players (7), and Sedentary subjects (7). All of the athletic groups were tested during their regular playing season and the sedentary subjects were tested during the same period. Obviously there were differences between the three athletic groups with regards to training duration, training frequency and training type.

The exercise test was conducted on a Monark bicycle ergometer at a pedaling rate of 60 rpm, with a power load of 900 kpm/min. An open circuit method, adapted for the on-line analysis of end-tidal  $\text{CO}_2$  samples, was used for respiratory gas analysis. Heart rate was also recorded.

The test method of Sears et al. had necessitated only the analysis of end-tidal  $\text{CO}_2$  and collection of a sufficient volume of expired gas for analysis of  $F_{\text{E}}\text{O}_2$  and  $F_{\text{E}}\text{CO}_2$ . No volumetric determinations were necessary. However, in the present study  $V_{\text{E}}$  was recorded in order that  $\text{VO}_2$  could be determined. Therefore, the typical open circuit, Douglas bag, method was used with the addition of on line analysis of end tidal  $\text{CO}_2$  analysis for each breath during collection period. To take end tidal  $\text{CO}_2$  data, a small hole was drilled in the face valve as close to the mouth as possible and expired gas constantly drawn off through the  $\text{CO}_2$  analyzer at a flow rate of 500 ml./min. Heart rate was also recorded.

Data collected included, therefore,  $F_{\text{A}}\text{CO}_2$ ,  $F_{\text{E}}\text{CO}_2$ ,  $F_{\text{E}}\text{O}_2$ ,  $V_{\text{E}}$ , and Heart Rate, and from these the following were determined, OEF, AVF,  $\text{VO}_2/V_{\text{A}}$ , Heart Rate, and  $\text{VO}_2$ .

In order to compare the differences between athletic and sedentary groups, analysis of variance was used, with individual  $t$  tests employed to investigate the relationship between individual groups. The type of  $t$  tests employed was determined by the result of a between-group variance test.  $P < .025$  was used to signify statistical differences between groups.

Heart rate during exercise had been obtained purely to confirm that the athletic groups were statistically different from the sedentary group with regard to fitness level. Results showed that all three groups of athletes exhibited heart rates which were significantly lower than those of the sedentary group.

Intergroup comparison of the  $\dot{V}O_2/V_A$  ratio, OEF, and AVF revealed that in all cases significant differences existed between the three athletic groups and sedentary group, but that few differences existed between the different athletic groups. Athletes had a higher  $\dot{V}O_2/V_A$  ratio, and higher OEF, and a lower AVF than did the sedentary subjects, (See Figure I).

Both the increased OEF and decreased AVF were contributory to the increase in the  $\dot{V}O_2/V_A$  ratio exhibited by the athletic groups. It was theorized that the higher athletic OEF could have been the result of either a facilitated lung diffusion or a reduced  $V_E$ .  $V_E$  measurements had been recorded and did show the athletic groups to have a lower value than the sedentary subjects. Although  $D_L$  was not directly measured in this investigation, it could have had an augmenting effect

AVF was found to be significantly lower in the athletic groups than in the sedentary groups. This was an unexpected finding but there are two explanations which could account for it.

At relatively high work loads, forced ventilations occurs, as a result of which the end expiration airway resistance increases. This has been shown to enlarge the functional residual capacity at the expense of the inspiratory as well as expiratory reserve volumes. The resultant effect on the composition of the alveolar air of a smaller effective ventilation is an increased end-expiration  $\text{CO}_2$  containing space remaining in the lungs. This volume will result in an increased  $\text{CO}_2$  fraction in the expired air. By the same token, the alveolar  $\text{CO}_2$  fraction, being determined by the arterial  $\text{CO}_2$  fraction in healthy subjects, should be expected to remain relatively constant. The resultant effect could be an increased  $F_{\text{E}}\text{CO}_2$  and a constant  $F_{\text{A}}\text{CO}_2$ , hence causing the AVF to be increased.

Another possible explanation concerns the distribution of ventilation. There are, evidently, regional differences in distribution of ventilation from moment to moment within the lungs, and exercise results in a more uniform ventilation. Therefore, if a positive relationship exists between uniformity of ventilation and relative exercise intensity, sedentary subjects, who exercise closer to their maximum, may have an even more uniform ventilation than do more fit subjects.

There were small but significant differences between some athletic groups. The basketball players had a significantly lower exercise heart rate than the football players and also a significantly higher OEF than the rugby players.

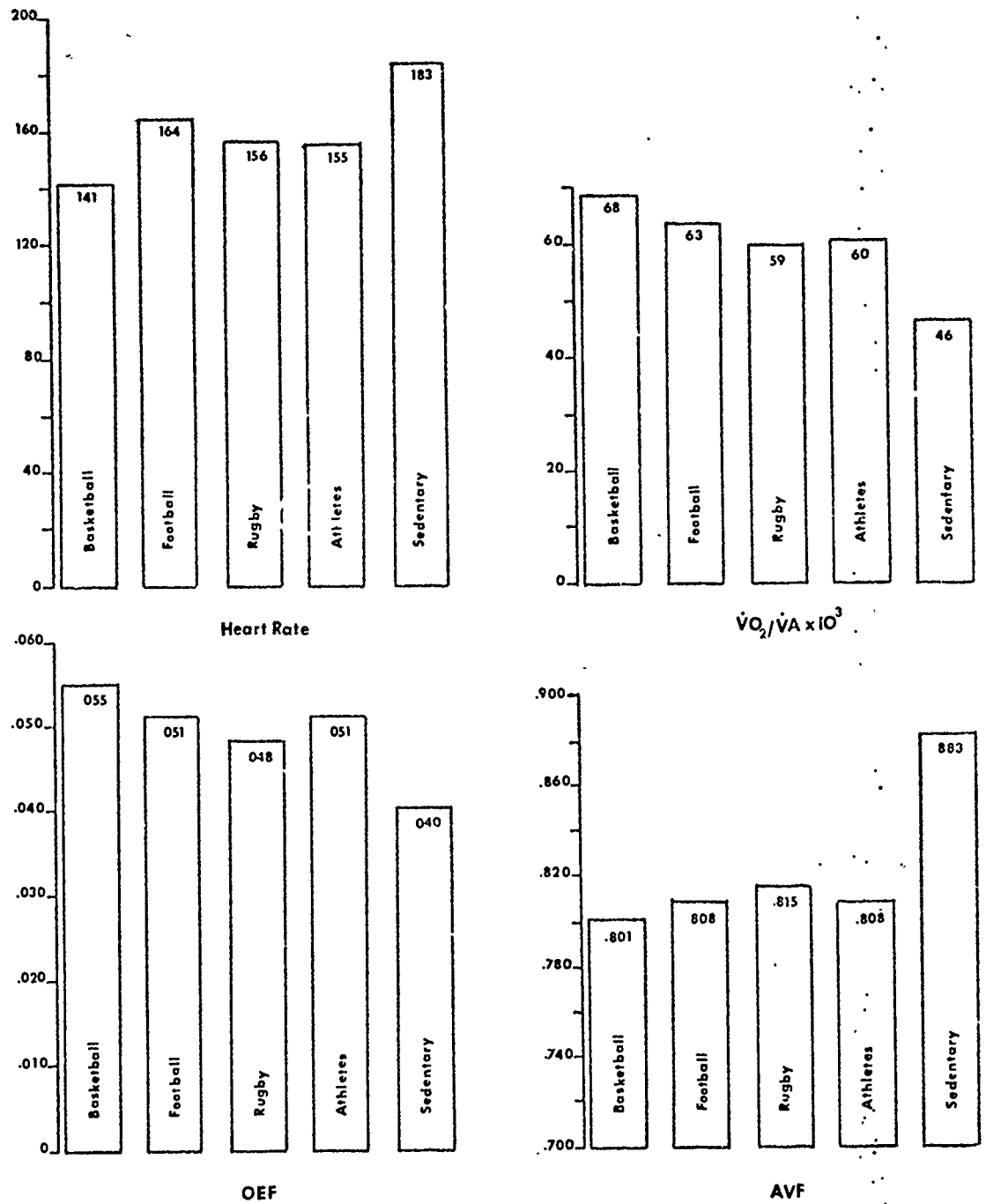


FIGURE I

HISTOGRAM OF THE STEADY STATE SUBMAXIMAL EXERCIS. HEART RATE,  $\dot{V}O_2/\dot{V}A$ , OEF, AND AVF FOR ATHLETIC AND SEDENTAR GROUPS

## DERIVATION OF THE OXYGEN UPTAKE FROM ALVEOLAR VENTILATION RATIO

The following is a brief explanation of the derivation of the oxygen uptake from alveolar ventilation ratio as developed by Sears et al.<sup>1</sup> Standard symbols are used where not specifically defined. Basic pulmonary expressions are those of Comroe et al.<sup>2</sup> It is assumed in the following description that all volumes and fractions are measured over the same time period.

Expired air is composed of a combination of alveolar air and dead space air:

$$(1) \dot{V}_E = \dot{V}_D + \dot{V}_A$$

Physiological dead space can be defined as that air which does not gain CO<sub>2</sub> nor lose O<sub>2</sub> during ventilation. All CO<sub>2</sub> in the inspired air, therefore, with the exception of a small amount (0.034%) from the inspired air, is the result of CO<sub>2</sub> being gained from the blood across the blood-air interface in the alveoli:

$$(2) \dot{V}_{E\text{CO}_2} = \dot{V}_E \times F_{E\text{CO}_2}$$

$$(3) \dot{V}_{E\text{CO}_2} = \dot{V}_A \times F_{A\text{CO}_2}$$

Combining expressions (2) and (3):

$$(4) \dot{V}_E(F_{E\text{CO}_2}) = \dot{V}_A(F_{A\text{CO}_2})$$

or: 
$$(5) \dot{V}_A = \dot{V}_E(F_{E\text{CO}_2}/F_{A\text{CO}_2})$$

Oxygen uptake can be expressed as:

$$(6) \dot{V}_{O_2} = (\dot{V}_I \times F_{I\text{O}_2}) - (\dot{V}_E \times F_{E\text{O}_2})$$



The oxygen uptake from alveolar ventilation equation was derived in order to determine the fraction of  $O_2$  removed from a unit volume of alveolar air and is the ratio  $V_{O_2}/V_A$ , which is obtained by combining expressions (6) and (5):

$$(7) \quad V_{O_2}/V_A = (\dot{V}_I F_{I O_2} - \dot{V}_E F_{E O_2}) / \dot{V}_E (F_{E CO_2}/F_{A CO_2})$$

Provided that all gas volumes and fractions are measured under the same environmental conditions (ATPD, STPD, BTPS, etc.), the ratio can be considered dimensionless.

Correction for the volume differences between inspired and expired air is readily obtained by means of the  $N_2$ -ratio method

$$(8) \quad \dot{V}_I = \dot{V}_E (F_{E N_2}/F_{I N_2})$$

Substituting for  $V_I$  in (7):

$$(9) \quad V_{O_2}/V_A = [(\dot{V}_E F_{E N_2}/F_{I N_2}) F_{I O_2} - \dot{V}_E F_{E O_2}] / \dot{V}_E (F_{E CO_2}/F_{A CO_2})$$

$V_E$  in the above equation (9) cancels out and, for the purpose of this study,  $F_{I O_2} = 0.2094$  and  $F_{I N_2} = 0.7903$ .

Therefore:

$$(10) \quad V_{O_2}/V_A = [0.265(F_{E N_2}) - F_{E O_2}] / F_{E CO_2}/F_{A CO_2}$$

But: 
$$(11) \quad F_{E N_2} = (1 - F_{E CO_2} - F_{E O_2})$$

Therefore:

$$(12) \quad V_{O_2}/V_A = [0.265(1 - F_{E CO_2} - F_{E O_2}) - F_{E O_2}] / (F_{E CO_2}/F_{A CO_2})$$

The  $V_{O_2}/V_A$  ratio can be calculated, therefore, by determination of but three gas fractions:  $F_{A CO_2}$ ,  $F_{E CO_2}$ , and  $F_{E O_2}$ .

1. Sears, D. F., W. A. Byrd, P. J. Maud, and W. W. Waring, Criteria to determine drug effects on pulmonary function in children, Agents and Actions, 3/4: 223-228, 1973.
2. Comroe, J. H., R. E. Forster, A. B. Dubois, W. A. Briscoe, and E. Carlsen, The Lung. Chicago: Year Book Publishers, Inc. 1955, pp. 171-212.