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$\dot{V}O_2$ max During Progressive and Constant Bicycle Exercise in Sedentary Men and Women*

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Summary. $\dot{V}O_2$ max, as obtained by five cycloergometric test protocols, was studied in 14 normal sedentary subjects: seven women (from 21–35 years) and seven men (from 21–48 years) who carried out four ($n = 14$) or five ($n = 8$) of the following exercise programmes: triangular tests, which consist of increasing the load (1) 20 W/min; (2) 30 W/3 min, rectangular tests at constant load; (3) the highest load which the subject could maintain for about 10 min (MSP + 20 W); (4) maximal supported power (MSP) during 20 min; (5) trapezoidal test, consisting of a rectangular exercise of 40 W (10 min), followed test no. 2. Exercises were performed on a cycle ergometer, while $\dot{V}_E$, $\dot{V}O_2$, $\dot{V}CO_2$, f, and fH were continously measured with an open circuit system.

In women, the $\dot{V}O_2$ max ($\bar{x} \pm$ SEM) was lower (36.5 ± 2.1 ml $\cdot$ kg^{-1} $\cdot$ min^{-1}) than in men (48.7 ± 3.6 ml $\cdot$ kg^{-1} $\cdot$ min^{-1}). The highest ventilation rate observed during exercise for the whole group ($\dot{V}_E = 101 + 13$ l $\cdot$ min^{-1}) was always lower than the maximal voluntary ventilation (MVV = 144 ± 13 l $\cdot$ min^{-1}, $p < 0.001$). $\dot{V}O_2$ max strongly correlated with lean body weight, VC, FEV_1, and MVV.

In spite of the significant differences between the maximal load level sustained with the first three tests, the $\dot{V}O_2$ max values were not significantly different. Moreover, there exists an excellent correlation between them. It appears that neither the absolute load sustained in the tests, nor the duration nor intensity of the submaximal load which preceded the maximal level (tests 1, 2, and 5), influence the value of $\dot{V}O_2$ max.

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Maximal oxygen consumption ($\dot{V}O_2$ max) is a variable which interests physiologists, pneumologists, and specialists in sports medecine [2, 3, 5, 6, 18, 23, 26, 27, 29, 30]. Several methods have been reported for determining $\dot{V}O_2$ max. Indirect methods [13] are not very reliable in sedentary subjects and direct methods should be more satisfactory [13, 21, 23, 24, 26, 28]. However, published works on the relationships between the different exercise tests used to measure $\dot{V}O_2$ max are rare [8, 18, 22].

Frequently, tests are used in which the load is progressively increased to the exhaustion limit of the subject [4–6, 8, 17, 21, 23, 28, 30]. Some authors use a constant load in such a way that the limit of exhaustion is reached after 2–8 min of exercise [3, 9, 10, 12, 22, 25, 31]. Comparative studies of the results obtained in the two methods described are not readily available, and most of them were carried out on treadmill. In Europe the cycle ergometer is most commonly used in cardiorespiratory functional tests, and raises the question of whether the different methods for measuring $\dot{V}O_2$ max on a cycle give different results. Since the European Economic Community (EEC) workshop standardises triangular exercises at a progressively increasing load [2, 5, 6], the aim of this study is to compare, in a group of normal sedentary men and women, the measurement of $\dot{V}O_2$ max, carried out using three progressive tests which we compare to a rectangular reference test [9, 12, 25].

Subjects and Methods

Fourteen untrained subjects volunteered for this study. None were currently performing physical training and 13 of them had never participated in a sporting competition. There were seven women (mean age 27 years ranging from 21–35 years), and seven men (mean age 29 years, ranging from 21–48 years). Each subject answered a standard questionnaire and underwent clinical, electrocardiographic, and spirographic examinations. The lean body weight and fat weight were determined using anthropometric mesures [20, 32].

The spirographic examination consisted of vital capacity (VC), forced expiratory volume in 1 s (FEV_1), and maximal voluntary ventilation (MVV); MVV was always measured at respiratory rates higher than 40 breaths per min. Three to five maximal expiratory and inspiratory flow volume curves were obtained, to allow the masurement of peak expiratory flow (PEF) and peak inspiratory flow (PIF) and maximal expiratory flow at 50% of VC. The volume and flow measurements were made using a Jaeger Ergopneumotest, whose computer registers the maximal values for at least three manoeuvres. Each subject carried out a series of exercise tests which are represented in Fig. 1:

1. A triangular test, in which the initial load of 20 W is progressively increased every minute until exhaustion of the subject. The values during the last 30 s of the final step were used as $\dot{V}O_2$ max.

2. A triangular test, in which the initial load is 30 W and progressively increased every 3 min [2, 5, 13]. The maximal tolerated power over 3 min (MTP) corresponds to the $\dot{V}O_2$ max if the subject stops pedalling at the end of that particular step. However, if the subject carries on to a higher load even though he is unable to maintain the effort for 3 min (MTP + 30 W), this maximal level is considered $\dot{V}O_2$ max. The values during the last minute of MTP or during the last 30 s of MTP + 30 W were retained in this case.

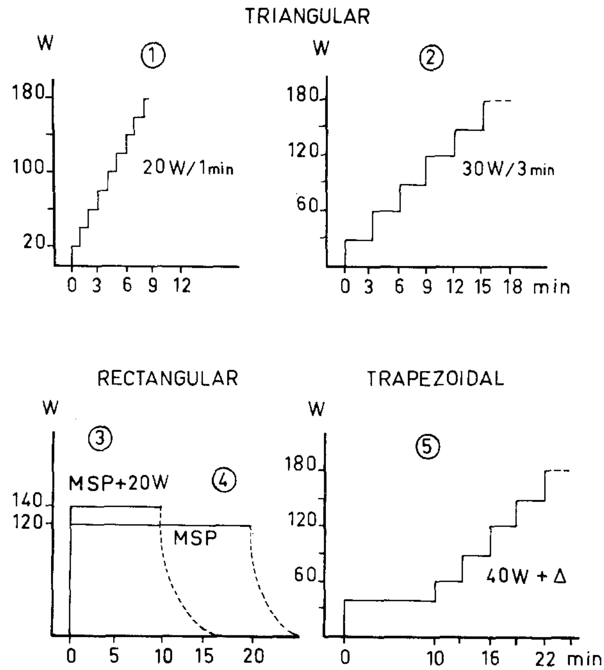

Fig. 1. A schematic representation of the various ergospirometric methods used in the determination of $\dot{V}O_2$ max

3. A maximal rectangular test, consisting of the maximal supported power (see below) plus 20 W (MSP + 20 W) which cannot be maintained for 20 min. In fact, subjects usually have to give up this exhaustive test at roughly the 10th min of exercise, which still permits us to obtain the $\dot{V}O_2$ max. The values during the last minute of exercise are used.

4. A rectangular test, consisting of maximal supported power (MSP) for 20 min, defined on ventilatory [9], cardiorespiratory [25], and metabolic criteria [12] which verges on anaerobiosis. The values of $\dot{V}O_2$ during the last 10 min were averaged and retained. Inspite of their exhaustive nature, tests 3 and 4 have been used in this laboratory for more than 20 years (> 60,000 tests) without any serious accident.

5. A trapezoidal test, which was conceived to allow the analysis, of cardiorespiratory responses during a submaximal exercise, but performed during stable conditions and at $\dot{V}O_2$ max. The test began at 40 W for 10 min, then, without interruption, was followed by a triangular test of 30 W/3 min (test no. 2) but whose initial load was 60 W.

Before starting the tests, the subjects were asked to make a manual signal when they experienced signs of fatigue, or before stopping the exercise. Verbal encouragement was given to urge the subjects to maintain their maximal effort for another 30 s, or even another 1 or 2 min, depending on the test.

All subjects performed at least four maximal tests. They were separated by an interval of not less than 24 h and performed at the same time of day. The triangular exercise (test no. 2) was chosen as the initial test to obtain the correct MSP and MSP + 20 W values. The remaining tests (no. 1, 3, and 4) were used randomly. After completing the first four tests, eight subjects agreed to perform the trapezoidal exercise test (no. 5). The results obtained from these eight subjects showed that there was no significant difference between the $\dot{V}O_2$ max values obtained in tests 2 and 5 and, moreover, that there was an excellent and significant correlation between them ($r = 0.998$, $p < 0.001$). Consequently, we have retained the values for test no. 2. Ventilation ($\dot{V}_E$) with its two components, frequency (f) and tidal volume ($\dot{V}_T$), and the respiratory exchanges, uptake $\dot{V}O_2$ and CO_2 output ($\dot{V}CO_2$), were all measured continuously using a Jaeger Ergopneumotest (EP) with a Dataspir

EDV 70 data processing system (E. Jaeger, Würzburg, FRG). The values were registered every 30 s and then every 15 s during the last 2 or 3 min. The electrocardiogram was continuously monitored on the screen and registered (Siemens 3T Cardiostat) during the last 15 s of each step in the triangular exercise tests (no. 1, 2, and 5), and during the last 15 s of the 3rd, 5th, 10th, 15th, and 20th min of MSP and of the 1st, 3rd, 5th, 6th, 7th, 8th, etc. . . . min until the end of MSP + 20 W.

Before each spirographic or ergometric measurement the pneumotachograph and CO_2 and O_2 analysers were calibrated. At the end of the series of tests the subjects completed a simple questionnaire on subjective tolerance (feasible or arduous), the length of the test, immediate recuperation (30 min); signs of fatigue 24 h later and finally preference of the tests carried out.

The paired *t*-test and correlation coefficients between the variables constitute the statistical analysis.

Results

There were no adverse clinical effects during the various maximal tests.

The average ($\bar{x} \pm$ SEM) age, physical characteristics, lean body weight and fat weight, expressed in kg, are shown in Table 1. The values for real weight were (+10 p. 100) greater than the calculated ideal weight (by the Lorentz formula), thus there were no cases of true obesity (< 30%) in the group studied. Weight, height, and lean body weight were significantly lower in the women.

Table 2 shows the mean values for volumes and flows. In general, in the women, the values for volumes and flows were lower by 20%–25% than those of the men (with the exception of $\dot{V}_E$ max 50). VC was always higher than the predicted values (EEC) [1] and the Tiffeneau relationship (FEV_1/VC) always exceeded 80% (these calculated values are not shown in Table 2).

Figure 2 shows the average values and individual variations at the maximal levels of power and oxygen uptake, for the corresponding levels during the two progressive and the two rectangular tests. In watts, the highest power observed was in triangular test no. 1 (20 W/min) followed in decreasing order by test no. 2 (30 W/min), test no. 3 (MSP + 20 W), and finally test no. 4 (MSP), which was

Table 1. Physical characteristics of the subjects studied

	Age year	Weight kg	Height m	BSA m^2	IW	LBW
Men (*n* = 7)						
$\bar{x}$	29	67	1.72	1.80	66.7	59
SEM	3.9	2.9	1.12	0.05	2.0	2.2
Women (*n* = 7)		*	*	**	***	***
$\bar{x}$	27	56.8	1.62	1.60	53.5	45.3
SEM	2.1	3.1	0.13	0.06	2.6	2.5

* = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$
BSA, Body surface area
IW, Ideal weight, as calculated by Lorentz
LBW, Lean body weight, calculated by anthropometric mesures [20, 32]

slightly submaximal. In spite of the important and significant differences between the power levels attained in the first three tests (1–2, 2–3, 1–3, $p < 0.001$) the maximal oxygen uptake was practically the same in tests 1, 2, and 3 for the group as a whole, or for the men or women separately. There was no significant difference in $\dot{V}O_2$ between tests 1–2, 2–3, 1–3, and 1–5. The $\dot{V}O_2$ at MSP were lower than $\dot{V}O_2$ max. According to Durand and Saunier [9] the

Table 2. Volumes and flows measured

	VC	FEV$_1$	PEF	PIF	$\dot{V}_E$ max 50	MVV
	1	$1 \cdot s^{-1}$				$1 \cdot min^{-1}$
Men ($n = 7$)						
$\bar{x}$	5.18	4.57	10.13	7.98	4.26	167
SEM	0,16	0.13	0.44	0.52	0.23	7.3
Women ($n = 7$)	**	**	*	**		**
$\bar{x}$	3.93	3.45	8.03	5.57	4.18	121
SEM	0.26	0.24	0.33	0.29	0.31	8.74

* = $p < 0.01$; ** = $p < 0.001$
PEF, Peak expiratory flow
PIF, Peak inspiratory flow
MVV, Maximal voluntary ventilation
$\dot{V}_E$ max 50, maximal expiratory flow at 50% of vital capacity

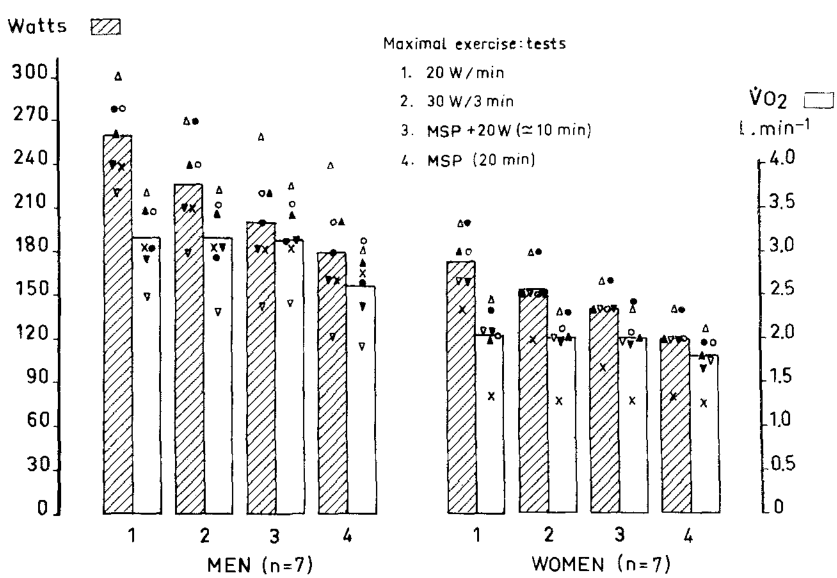

Fig. 2. The maximal powers observed in four tests were significantly higher (in decreasing order) in tests 1, 2, 3, and 4. In spite of the important and significant differences between those power levels, the maximal oxygen uptake was practically the same in tests 1, 2, and 3, in both the men and the women

Table 3. Maximal values observed in the whole lot of tests. The mean values retained correspond to the maximal values in the first four tests carried out on each subject

	$\dot{V}O_2$		fH Puls · min^{-1}	O_2 Pulse ml · $systole^{-1}$	$\dot{V}_E$ l · min^{-1}
	kg	kg (LBW)			
Men ($n = 7$)					
$\bar{x}$	48.7	55.2	189	17.1	125
SEM	3.6	3.9	4.5	1.1	12.3
Women ($n = 7$)	**	*		***	**
$\bar{x}$	36.5	44.8	193	10.7	77.3
SEM	2.1	2.4	3.1	0.8	3.7

fH, Heart rate
LBW, Lean body weight
* = $p < 0.05$; ** $p < 0.01$; *** = $p < 0.001$

oxygen uptake at 20 W is approximately 0.25 l · min^{-1}, ($\dot{V}O_2 = 0.250 + 0.0125$ W).

Analysis of the individual values during the four maximal tests (1, 2, 3, and 5) shows that the respiratory quotient (RQ) was always higher than 1, that the respiratory equivalent for O_2 ($RE = \dot{V}_E/\dot{V}O_2$) was higher than 30 and that heart rate (fH) was maximal (220-age). These criteria indicate that true maximal levels were attained. Considering the maximal fH in all subjects and a lower $\dot{V}O_2$ max in the women, it appears that in the latter the amount of oxygen transported by systole was smaller than in males (Table 3).

Table 3 gives the average values of the highest $\dot{V}O_2$ found throughout the series of tests, expressed in term of kg body weight and kg lean body weight. The women have lower values than men (−20%). The correlation between $\dot{V}O_2$ max and body weight ($r = 0.605$, $p < 0.05$) or body surface area ($r = 0.620$, $p < 0.05$) is weaker than the correlation between lean body weight and $\dot{V}O_2$ max ($r = 0.723$, $p < 0.01$). Correlations are more significant between $\dot{V}O_2$ max and VC ($r = 0.734$, $p < 0.01$), FEV_1 ($r = 0.784$, $p < 0.001$), and MVV ($r = 0.765$, $p < 0.01$). The correlation between peak expiratory flow ($r = 0.544$, $p < 0.05$) and peak inspiratory flow ($r = 0.519$, n.s.) is weak. The highest ventilation observed during exercise (Table 3) was always lower than the MVV (Table 2) reaching approximately 70% of the latter. Again, the level was lower in women (64%) than in men (76%).

Discussion

The most notable feature of our results is the excellent reproducibility of the $\dot{V}O_2$ max in spite of the diversity of the tests used (Table 4, Fig. 2). These results are similar to those noted by other groups, who, using a treadmill or a cycle ergometer, found no difference in $\dot{V}O_2$ max between continuous, intermittent or progressive tests [7, 8, 14–17, 22, 24, 26]. This indicates that $\dot{V}O_2$ max is not

Table 4. Correlations between maximal values of $\dot{V}O_2$ and $\dot{V}_E$ observed during the different tests. There exists a very close correlation between the $\dot{V}O_2$ max obtained in tests 1, 2, and 3. The $\dot{V}_E$ is also very closely correlated in these three tests

$n = 14$	Test no. 1 (20 W/min)		Test no. 2 (30 W/3 min)		Test no. 3 (MSP + 20 W)	
	$\dot{V}_E$	$\dot{V}O_2$	$\dot{V}_E$	$\dot{V}O_2$	$\dot{V}_E$	$\dot{V}O_2$
Test no. 1 (20 W/min)						
$\dot{V}_E$			0.963**			
$\dot{V}O_2$				0.994**		
Test no. 3 (MSP + 20 W)						
$\dot{V}_E$	0.966**		0.949**			
$\dot{V}O_2$		0.995**		0.997**		
Test no. 4 (MSP)						
$\dot{V}_E$	0.762*		0.845**		0.809*	
$\dot{V}O_2$		0.980**		0.977**		0.977**

* $p < 0.01$; ** $p < 0.001$
MSP, Maximal supported power during 20 min

affected by the cumulative effects of submaximal effort which preceed maximal effort (tests 2 and 5). Knowlton et al. [19] have shown that the oxygen uptake is not affected by a warming-up session: any advantage gained by warming up can be attributed to neuromuscular or orthopedic effects [19]. Furthermore, their results suggest that $\dot{V}O_2$ max is not necessarily associated with a given power. Table 4 shows significant correlations between $\dot{V}O_2$ max in the three maximal tests in spite of significant differences in maximal power. Thus, in the progressive exercise there is a certain delay relative to the values observed in the rectangular exercise. A comparison between tests 1 and 2 (Fig. 3) shows that although test 1 was performed at the same power, or at a power consistently higher than test 2 (30 W/3′), the $\dot{V}O_2$ observed was either lower or equal to that observed in test no. 2. In test no. 2, $\dot{V}O_2$ approached that observed in the rectangular tests, up to levels demanding 80% of $\dot{V}O_2$ max. However, above this level, when $\dot{V}O_2$ was almost attained, the differences between the two levels increased and for the same power $\dot{V}O_2$ was generally lower in test no. 2 than in test no. 3 (MSP + 20 W). These significant differences can in part be attributed to the response of the ergometer cycle or of the Ergopneumotest (EP). Verification of the calibration on the ergometer cycle by mechanical means has eliminated the possibility of inaccuracy in the loads selected. The EP's time response measured at 120 $l \cdot min^{-1}$ ventilation and a frequency of 40 cycles occurs at 30 s. Spiro et al. [27] compared $\dot{V}O_2$ at the end of the first min to the 6th min in a group of 20 normal but sedentary subjects. Oxygen uptake represented only 61% of the latter level in exercise demanding oxygen uptake of 1 $l \cdot min^{-1}$, and 56% when the level imposed was 50% of the maximal effort (1.5 $l \cdot min^{-1}$).

Thus, there exists a delay in oxygen uptake in test no. 1. Young and Woolcock [33], measuring arterial blood gases every 15 s during the first 90 s of effort, found, in nine normal subjects, hypoxemia during exercise, whereas the

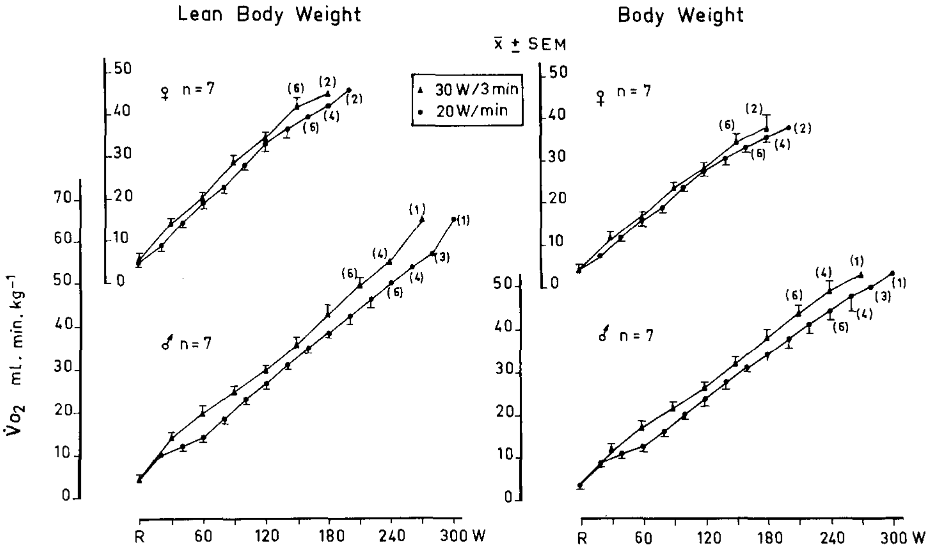

Fig. 3. At the same power, $\dot{V}O_2$ was lower in test 1 (20 W/min), than in test 2 (30 W/min). Consequently, there existed a delay in O_2 uptake, in the triangular exercise, when the time taken to increases the loads was shorter

$PaCO_2$ level remained similar to that at rest. We have not sought to verify this phenomenon, but our results suggest that during the triangular 20 W/min exercise a steady state can never be attained between the energy need and the oxygen uptake, as the time is too short for adaptation to occur.

Finally, Wasserman and Whipp [30] have found that the anaerobic threshold (AT) appeared later when the load increase occurred every minute instead of every 4 min. Due to this delay, they prefer to define the AT in terms of $\dot{V}O_2$ rather than in terms of power. They state that the AT always appears at the same $\dot{V}O_2$ level, without relation to the time taken to increase the steps [30], which implies a $\dot{V}O_2$/W evolution similar to that noted here (Fig. 3).

When a subject starts an exercise at constant load, a stable heart rate (*fH*), $\dot{V}_E$ and respiratory exchanges are only achieved after several minutes at low power values [11, 16, 25, 27, 31]. This adaptation can be described as a simple exponential function in young normal subjects. At moderate and high powers, this adaptation is less well defined and, in the case of maximal exercise, a stable level is never reached [31]. In stable conditions the oxygen uptake translates as O_2 for metabolic needs, whereas in unstable conditions the $\dot{V}O_2$ measured at the mouth gives a falsely low impression of the metabolic needs. On the other hand, during exercise no. 2, a stable $\dot{V}O_2$ level seems to be acquired for powers demanding up to 80% of $\dot{V}O_2$ max as the 3 min of each step is approached. No information exists in the literature on the evolution of cardiorespiratory variables during maximal power maintained for more than 5 or 6 min.

Whipp and Wasserman [31] observed that the time taken to attain a stable level increases with the increase in power, at levels below the AT. They observed a difference in $\dot{V}O_2$ between the 3rd and 6th min at a constant load at high power levels. They concluded that a stable level had still not been attained at the end of the 6th min. In fact, they found a second $\dot{V}O_2$ exponential factor at very high power levels. The group at Nancy [9, 12, 25] has observed that during MSP a stable respiratory state was only attained after 8–10 min [9, 25]. But even in these circumstances anaerobiosis was being approached as lactate increased between the 10th and 20th min of exercise, whereas it tended to decrease for powers below MSP [12]. In this work we have calculated the percentage of the $\dot{V}O_2$ at min 1, 3, and 5 in relation to the 10th min of MSP, or the last minute of MSP + 20 W. The difference, which is very significant during the 1st min (49 ± 11 p. 100), decreases progressively (82 ± 6 at the 3rd min and 91 ± 2 at the 5th min). These figures confirm the results of Whipp and Wasserman [31] that the real $\dot{V}O_2$ is not attained until after the 5th min. This shows that, for high powers, maintained only for 1–3 min, the steady state is not attained and thus the oxygen uptake is underestimated (Fig. 4). Furthermore, a single determination of $\dot{V}O_2$ max in a rectangular test after 2–5 min may result in an underestimation, of the "true" $\dot{V}O_2$ max.

As the $\dot{V}O_2$ max can be measured by any of the three maximal tests, method of choice depends on the objectives.

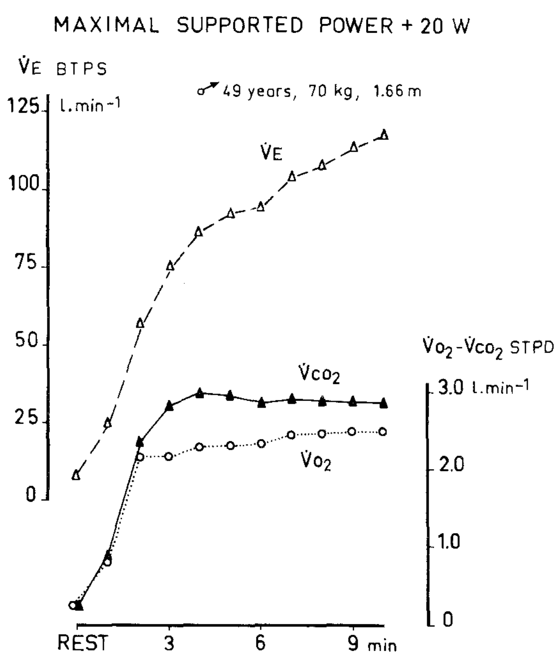

Fig. 4. From the 2nd min of MSP + 20 W, the respiratory quotient was higher than 1. The subject tried to compensate for anaerobiosis with involuntary progressively increasing ventilation. This allows to judge the subject's degree of cooperation. Also, the oxygen uptake appeared stable only after the 7th min

If a great number of subjects are to be studied or economic considerations are important [2], then exercise test no. 1 (Fig. 1) should be chosen. In one session of 10 min this test can determine $\dot{V}O_2$ max in co-operative subjects, and if the apparatus used (EP) has a rapid response time. However, the rapid increase in load gave a "generally" disagreeable subjective sensation at the end of exercise and during the first minutes of recuperation when compared to test no. 2. Also, the short time available between changing the loads means that the operator has little time to verify the correct functioning of the apparatus (cycle ergometer and EP) or the subjects well-being, especially the arterial pressure and ECG. In effect, this test demands two technical assistants.

Tests no. 2 (30 W/3′), takes between 20 and 30 min and allows the $\dot{V}O_2$ max to be measured in a single session. The 3 min levels allow better cardiorespiratory adaptation, as the progressive increase is interpreted by the subjects as a gradual warm-up. This test permits an analysis of the breaking point of ventilation [4, 6, 30] and taking in a given load, blood samples with more ease than in the test no. 1. It is easier for a technician to change the loads and to watch EP and the subject in this test. Time response of the analysing equipment is less important than in test no. 1.

In tests 1 and 2, if the subject does not give full co-operation, $\dot{V}O_2$ max may not be achieved. Verbal stimulation near the end of the exercise is necessary.

Finally, the maximal rectangular exercise is determined after finding the MSP. Its level is fixed as a multiple of 20 W [9, 25]. For the MSP, gasometric, metabolic, and even haemodynamic measurements could be carried out during 20 min of relatively stable respiration [9, 25]. *The MSP + 20 W (Fig. 4), which leads to the $\dot{V}O_2$ max in 10 min, allows the verification of the subject's co-operation. The $\dot{V}_E$ should increase progressively under the effects of anaerobiosis up until the end of the test.*

This exhaustive test was described by the subjects as being very disagreeable, but allows the technician ample time to survey both the human and mechanical elements. Normally, two or three vigorous exercises separated by an interval of 24 h are demanded, consequently this is expensive, and arduous for the subject. However, after completing test no. 2 it is simple to determine the level of MSP + 20 W and to verify the subjects degree of co-operation and thus the "real" value of $\dot{V}O_2$ max, both for sedentary and chronic pulmonary subjects [13]. The "real" $\dot{V}O_2$ max is indispensable for the functional tests in the "limited co-operation" cases, as well as for expert medical needs in the cardiorespiratory field.

From the results presented in this work we can conclude that:

1. In normal, untrained, co-operative subjects the $\dot{V}O_2$ max can be obtained directly using tests on a cycle ergometer at constant or progressively increasing power.

2. The $\dot{V}O_2$ values obtained using the four maximal tests (no. 1, 2, 3, and 5) do not differ.

3. In the progressive tests a delay in $\dot{V}O_2$ was seen. This explains why the $\dot{V}O_2$ max was the same in the various tests where there were important and significant differences in maximal powers.

4. The $\dot{V}O_2$ max values, in absolute and relative terms, were significantly lower for the women.

Further studies are necessary to establish any possible threshold between normality and pathology and also to analyse the functional significance (acid-base balance, respiratory exchanges, etc. . . .) in "limited co-operation" cases and in patients, at an apparent normal of $\dot{V}O_2$ max.

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