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Active and Passive Recovery from Maximal Aerobic Capacity Work*

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Summary. Thirteen subjects performed two identical maximal aerobic capacity tasks on the bicycle ergometer, at one time recovering while sitting absolutely quiet and once while continuing to pedal at the same RPM against minimal resistance. The heart rate, oxygen-debt pay-off, and carbon-dioxide expulsion curves during recovery were established. Comparison of the Active and Passive recovery data showed no difference above their respective levels of return ("Zero" load pedaling or resting), except for substantially slower pay-off of the "lactic" part of the oxygen debt.

Key-Words: Exercise — Oxygen Consumption.

When an athlete finishes an exhaustive endurance run he often keeps moving at a much slower rate. In laboratory work, on the treadmill or bicycle ergometer, the subjects are sometimes asked to keep on moving and to "taper-off" while recovering. Athletes, as well as exercise physiologists have found that this continued low-level activity may prevent nausea and fainting during the recovery phase [6, 11]. The presumed reason is that the venous return to the heart is aided by pumping action of the muscles. "Pooling" of the blood in the legs is thus prevented and recovery is thought to be faster.

Analysis of the recovering phase following heavy exercise should reflect the beneficial aspects of such "taper-off" aid to the circulation. It should be visible in the form of a faster heart rate recovery as well as in an increase in the rate of pay-off of the oxygen debt.

Method

Thirteen male students (age 18—23) were selected on the basis of their motivation and fitness level. They came from classes in "circuit training", or had experience in long distance running or cycling.

Three preliminary familiarization rides on a bicycle ergometer were completed before the actual test performances took place. During these preliminary rides the

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heartrates and oxygen uptake data were collected. From this it could be determined which "maximal load" would have to be used to "finish off" a subject between 4 and 7.5 min. Inability to continue at the pedaling rate of 50 RPM after less than 4 min was considered a result of muscular fatigue, rather than due to a circulatory-respiratory limitation. When, on the other hand, a subject was able to continue beyond 7.5 min, it was felt that other fatigue factors might have prevented the subject from reaching his "crest" oxygen uptake. The workload was then adjusted (at the next session, a week later) to bring about a maximal oxygen uptake capacity ride of about 5 min duration.

The test itself consisted of:

a) 20 min of quiet sitting on the bicycle ergometer;

b) 2 min of pedaling at 50 RPM and at a load that was approximately $^2/_3$ of the previously determined "maximal load";

c) between 4 and 7.5 min of pedaling at the maximal load (different for each subject). The ride continued until the subject, with all encouragement that could be given, could not continue to pedal at 50 RPM for the better part of a 15 sec interval.

d) 18 min of recovery, either sitting absolutely still with the feet on a bar at saddle height (Passive Recovery) or pedaling at 50 RPM against the minimum friction, or "Zero" load of the ergometer (Active Recovery).

The conditions were rotated from subject to subject in an attempt to neutralize a possible learning, or training, effect. The metabolic cost of pedaling at "Zero" level (needed for a baseline in the Active Recovery calculation) was determined in a separate session. The subject at that time rode (at "Zero" load) for 10 min. The data were collected between the 7th and 10th min, during the steady state.

The maximal time that the subject performed on the first of his conditions was used as his ride limit for the second condition, so as to make his rides identical. In the case that a subject could not reproduce the previously recorded time he was asked to return another time until he provided an identical ride. Performances were one week apart, on the same day, same time, four hours, or more, after a light meal.

Oxygen uptake, carbondioxide production, and heartrates were noted every 15 sec for three pre-exercise periods (20—18, 10—8, and 2—0 min before the command "Start" was given), and throughout the performance and the 18 min of recovery. The readings were dictated to a tape recorder and transscribed later. The latter method of recording made it possible for one person to read, at a fast pace, the

a) High Velocity/Low Resistance Gasometer (Parkinson Cowan);

b) Beckman C_2 oxygen analyzer (modified to take a constant flow of 270 cc/min, which produced a 95%-response time of 10 sec for a 5% O_2 change);

c) Harvard CO_2 analyzer (providing a 95%-response time of 25 sec for a 5% CO_2 change).

With the above rather rapid instrument response, coupled with the small changes that occur in oxygen and carbondioxide concentrations from breath to breath, it was felt that a simple shift in the time line after the data were collected provided enough of a correction to result in a representative set of data.

Heartrates were continuously recorded on an adapted electro-myograph.

Results and Discussion

The graphs representing the average oxygen debt recovery, carbondioxide production, respiratory quotient and heart rate curves, are presented in Fig. 1.

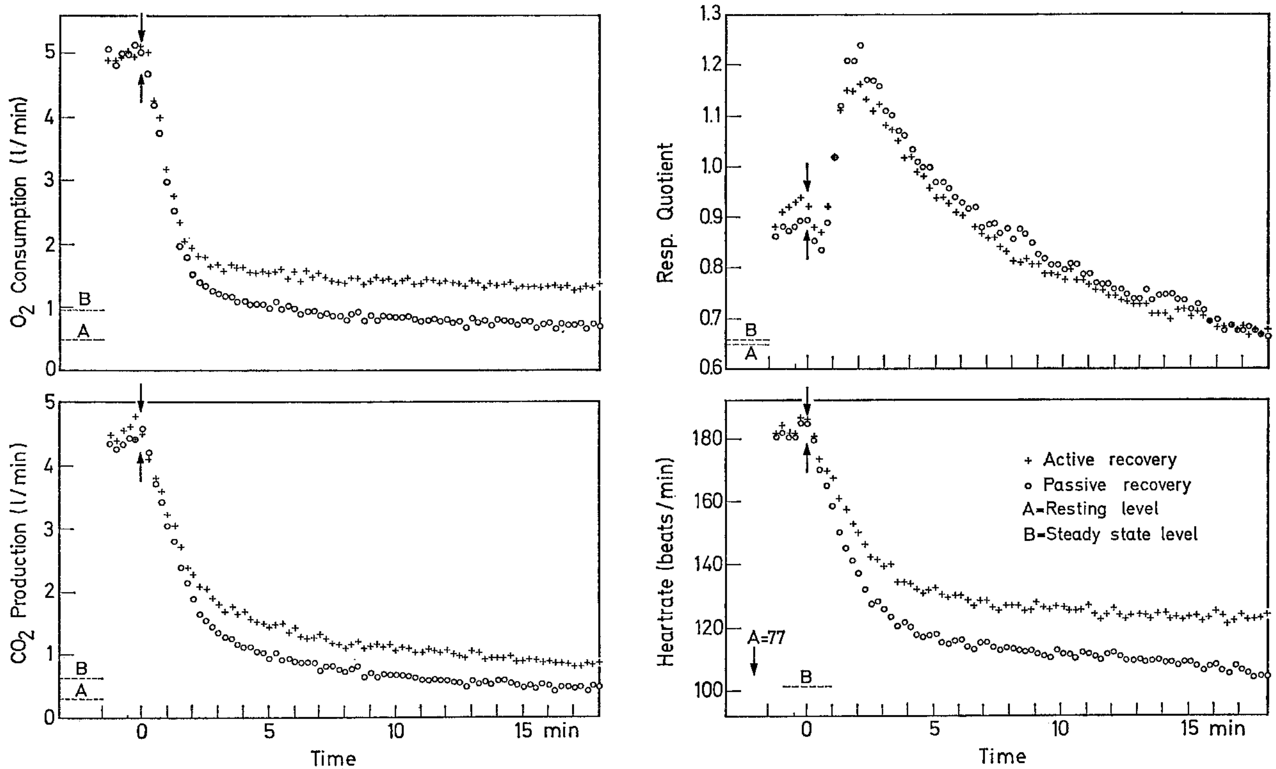

Fig. 1. Recovery from maximal aerobic capacity work starts at the O on the time axis. The baselines, to which the curves were assumed to return eventually, are marked A or B

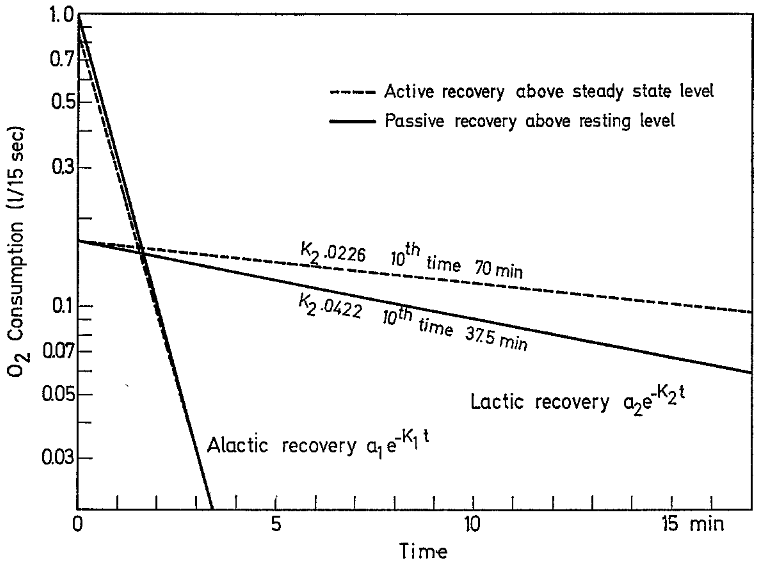

Fig. 2. Fractionation of the oxygen debt pay-off curves as they appear above the resting and "Zero" load pedaling level

It is obvious from these curves that the largest part of the recovery occurs very rapidly immediately after cessation of the exercise. The long-term recovery, however, occurs gradually, and is not completed even after 18 min of recovery. The difference (in recovery curves) between the Active and Passive Recovery conditions shows up very early (within 30—45 sec) in the heartrate, oxygen uptake and carbondioxide curves.

The respiratory quotient shows a sharp increase upon cessation of the exercise. This is the result of the fact that the uptake of oxygen is reduced faster than the exhalation of carbondioxide, creating a drastic change in the quotient.

Curve Analysis (Fig. 2). Recovery from work is considered to be complete when a resting homeostasis has been regained. Oxygen intake, during recovery, approaches the pre-exercise resting level in a two-component exponential fashion[1]. Net oxygen intake (above resting) at time t (min) of recovery is specified quite accurately by:

$$a_1 e^{-k_1 t} + a_2 e^{-k_2 t}$$

The first component expresses the *alactic* part and the second component the *lactic* part of the recovery curve. In the above expression a_1 and a_2 are the initial values of O_2 uptake (at the time work stopped and

1 Such fractionation of the oxygen debt pay-off, based on the early work of Hill et al. [5] and Margaria et al. [8] has been discussed in relation to their work by Henry and DeMoor [4], Joye [7] and others [9, 10].

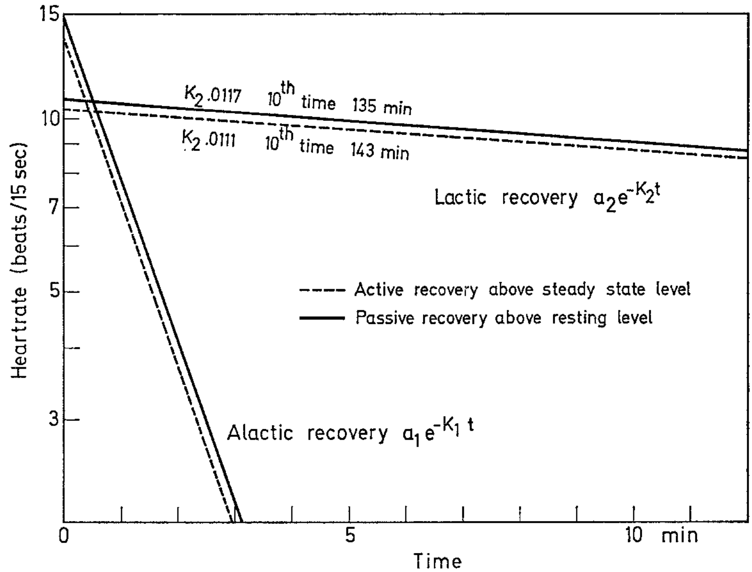

Fig. 3. Fractionation of the heartrate recovery curves as they appear above the resting and "Zero" load pedaling level

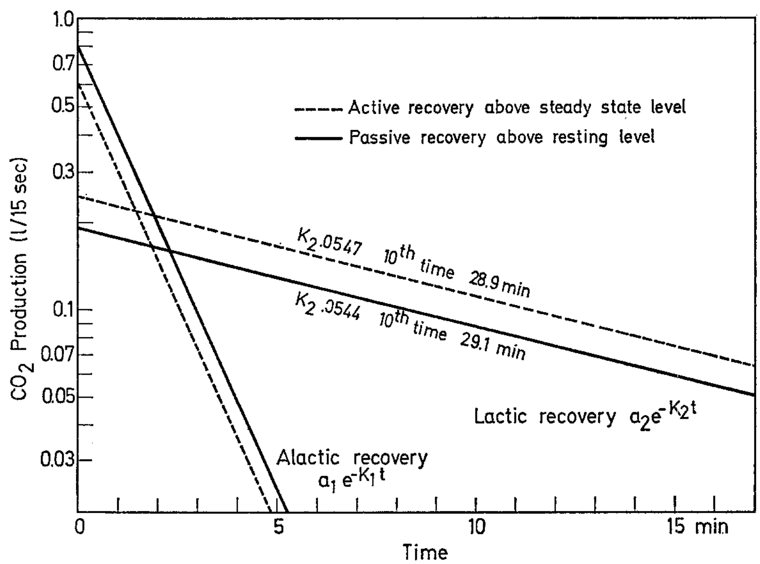

Fig. 4. Fractionation of the carbondioxide recovery curves as they appear above the resting and "Zero" load pedaling level

recovery started). The k_1 and k_2 denote the rate constants which determine how fast the O_2 uptake values approach an asymptotic value.

Table. *Recovery curve parameters*[a]

Parameters	Units	O_2 uptake		CO_2 prod.		Heartrate		Units
		Act.	Pass.	Act.	Pass.	Act.	Pass.	
Max.	l/min	4.990	4.791	4.497	4.262	183.8	182.4	b./min
A_O	ml/15 sec	1008	1107	872	990	24.2	25.9	b./15 sec
a_1	ml/15 sec	838	940	625	800	13.9	15.1	b./15 sec
k_1		0.7477	0.7656	0.4845	0.4611	0.4522	0.4434	
10th time	min	2.12	2.07	3.27	3.43	3.50	3.57	min
a_2	ml/15 sec	170	167	247	190	10.3	10.8	b./15 sec
k_2		0.0226	0.0422[a]	0.0547	0.0544	0.0111	0.0117	
10th time	min	70.0	37.5[a]	28.9	29.1	143	135	min
rest.	l/min	0.460	0.452	0.770	0.743	79.4	75.8	b./min
"O" load	l/min	0.922	—	0.650	—	93.6	—	b./min

[a] The only substantial differences were found in these parameters.
A_O is the sum of a_1 and a_2

Thus, a high numerical value of k shows a fast (steep) recovery. The e is the Naperian logbase.

Following the above method of fractionating, the net debt pay-off data from Fig. 1 were plotted on semi-logarithmic graph paper. It was then possible to draw a straight line through the points after min 5. This line extended to the left, crossing the vertical axis at a value a_2. The deviations of each plotted point from the line were plotted and a straight line, which crossed the vertical axis at a value a_1 was fitted to the latter. For the sake of clarity, the points have been omitted in Fig. 2, only the lines drawn as a best fit remain. Accuracy of fit by this method has been shown statistically in previous work by Henry and DeMoor [3, 4].

When the same method is used for the net heart rate and net carbon-dioxide recovery curves, we see that these also follow two-component exponential systems (Figs. 3 and 4), thus corroborating the work of Millahn and Helke [9] and Joye [7]. The curve parameters are presented in the Table.

Passive and Active Recovery. Although Fig. 1 shows a substantial difference in heart rate recovery between the two conditions, these disappear when the *net* heart rate recovery between the two conditions are compared, i.e., when we use the resting and "Zero" load pedaling level as baselines. Fig. 2 indicates identical "alactic", as well as "lactic", parts of the recovery. The differences between the a's and k's (Table) are negligible.

The above finding leads to the conclusion that the circulation is not affected by the Active Recovery condition, aside from meeting an increased level of metabolic performance at the "Zero" load level of pedaling, unless a stroke volume difference has gone undetected. An increase in the latter, however, would pump more blood through the lungs and then could show up as an augmentation of the O_2 uptake and CO_2 expulsion curves.

Comparison in these variable, however, fails to show any differences, except in the *lactic* part of the O_2 debt pay-off, and this only in a detrimental direction! (Fig. 2). Whereas the a_2's in the oxygen uptake curves are practically identical (i.e., starting after cessation of the work at values of 170 and 167 cc/15 sec), the k_2 in the Active Recovery condition is only about half of the value as its counterpart in the Passive condition (0.0226 and 0.0422). In terms of 10th time it shows that sitting quietly takes in 37.5 min, whereas pedaling requires 70 min, to accomplish a 90% recovery.

Why no differences are found in any of the parameters, except in the lactic part of the oxygen debt pay-off curve is at this time not clear. Careful viewing of the graphs in the work by Hansen [2] who had subjects increase and decrease their work output without stopping, shows the same trend. The termination of hard work is followed by an oxygen debt pay-off curve which approaches the new level of steady state uptake at a slower rate than in a "return to resting" condition. The "lactic" component has become slower.

It may be argued, that the use of resting values, which are obtained before the heavy work commences, as baseline, is erroneous. Christensen and Högberg [1] in their work on oxygen-deficit, maintain that in long lasting experiments the resting values for oxygen uptake may change due to the exercise itself. They noticed that the heartrate does not return as speedily to the new level as it does to the resting level. They find this a clear indication that the upright position, in which the low-level work was performed, is responsible.

Quaas and Lohs [10] in their study on the effect of active or passive pauses between workbouts also indicate that the calculation on which the establishment of oxygen-debt figures depend, may be biased because of the assumption of an erroneous (pre-work) baseline.

While the above points are certainly valid, a change in assumed baseline in the present study would only affect the "a" factor and not the slope (k) of the "lactic" components. The *approach* to the baseline value would remain of the same steepness, and still would show up as being substantially *slower* under Active Recovery conditions.

Apparently more studies are needed which are aimed at clarifying the circulatory-respiratory adaptations to shifts in workload. At this stage it can only be stated that the only important difference in whether or not an athlete "tapers off" lies in the level of work to which he returns. If the goal of the recovery phase is to recuperate as soon and as fully as possible for the next bout of hard work, it may be best to lie down and relax.

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