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# Oxygen consumption during submaximal exercises of equal intensity and different duration*

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With 1 Figure in the Text

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The question whether oxygen deficit and the repayment are equal in submaximal exercise has kept numerous investigators occupied. One view has been that they are the same in quantity[3, 4, 7] but dissenting voices have been heard[1, 2]. The latter investigators have pointed out that the exact determination of deficit and repayment are difficult since it is difficult to observe a true steady state. HENRY's[5, 6] studies on $O_2$ debt mechanisms also indicate a discrepancy between deficit and repayment, the latter being larger.

Whether deficit and repayment are equal, or unequal but proportionally related, may be determined for a particular intensity of exercise by statistical analysis of continuous oxygen intake records on an adequate number of subjects. By keeping the work load constant in intensity but varying in duration, it should be possible to determine the relationship between the deficit and repayment curves and also to see if the steady state oxygen intake varies with time.

## Method

The question of the most suitable work load is difficult. If it is too small, both deficit and repayment will be small and the relative error too large for effective analysis. If it is too high, cumulative debt from inadequate $O_2$ delivery to the tissues may prevent a steady state[6]. The results of CHRISTENSEN and HÖGBERG[2] indicated the difficulty of estimating the steady state level at the higher work loads. The lowest $O_2$ uptake rate obtained on the one subject in their series of treadmill runs was approximately 2.5 L/min. This work load may have been too high to permit a steady state. HENRY and DE MOOR[6] estimated that limitations in oxygen intake would be noticeable in the region of 3 L/min.

Preliminary investigation showed that riding a friction bicycle ergometer at a work rate of 640 mKg/min. (60 pedal rpm) resulted in an $O_2$ uptake rate of 1.7 L/min.

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This was well below the severity of exercise used by CHRISTENSEN, and was adopted for the present experiment.

Twenty-six male college students (17—24 yrs.) were tested twice on different days. The above work load was maintained for the duration of the work periods, consisting of five minutes (Test I) and ten minutes (Test II).

The oxygen consumption was determined at 10 sec. intervals by the open circuit method, employing a Max Planck Gas Uhr and a Beckman Model C continuous Oxygen Analyzer using the usual auxiliary apparatus and precautions as to flow rate and drying of the air. Air spaces in tubing, etc., were minimized. Following at least 15 min. of rest with the apparatus connected, data were collected during two minutes preceding the onset of work, during the work, and for seven minutes after cessation of the work. Room temperatures and other environmental conditions did did not vary appreciably.

## Results and Discussion

**Steady State.** Figure 1 indicates that the greatest average oxygen uptake rate during work did not exceed 1.8 L/min. A true steady state was not found, however, even at this relatively low physiological work level. A comparison in Test II of the average 10-second scores of minute 4 plus 5 with those of minute 9 plus 10 shows an increase of 154 cc oxygen intake for the two minutes. This is statistically significant (t = 5.8). The

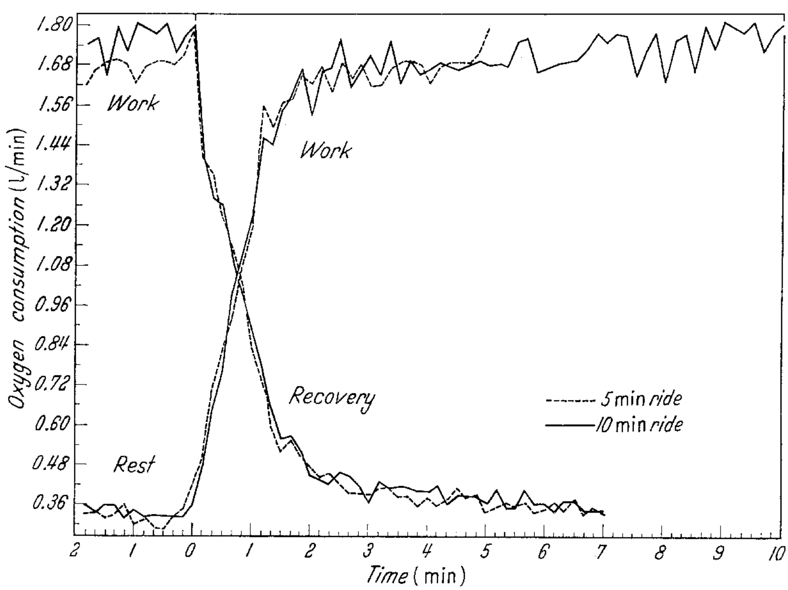


Fig. 1. Oxygen intake for Test I and Test II (obtained at 10 sec. intervals)

question remains how low the work load needs to be to maintain a truly steady state.

CHRISTENSEN and HÖGBERG[2] were of the opinion that "as soon as the work intensity is moderately high, the oxygen intake will increase during the whole period of work". They suggested that such factors as higher body temperature, decreasing carbohydrate oxidations and fatigue resulting in the use of less favorable muscle combinations are responsible for the slow increase. Perhaps the work load of the present experiment should be thought of as being "moderately high". HENRY and DE MOOR[6] observed a slow exponential rise in $O_2$ intake after the initial deficit in a 6-min. bicycle ergometer ride at a work load of 650 mKg/min. in 43 subjects.

**Deficit and Repayment.** The mean oxygen uptake curves (Fig. 1) show that the deficit part of the $O_2$ curve is a nearly exact mirror image of the repayment part. Any considerable quantitative discrepancy between measured size of deficit and measured size of pay-off must therefore be caused by differences in baselines or gradual increase in steady state income. However, the apparent equality of the mean deficit curve and the repayment curve at the present work load does not tell anything about individual responses. It is necessary to use correlation coefficients to examine individual differences.

**Correlations.** The individual deficit values may be computed as the difference between the intake for the last two minutes of exercise (used as a reliable estimate of potential $O_2$ intake) and the observed intake values for each minute, summed over the first three minutes for Test I and the first eight minutes for Test II. The individual pay-off values may be computed as the net $O_2$ intake during recovery, in amount above the pre-exercise resting rate, summed over the seven minutes of observed recovery. The correlation between Test I deficit and recovery is $r = .42$, and for Test II, it is .22. When the individual deficit values for Tests I and II are combined (using only the first five minutes of Test II), and the individual pay-off values for Tests I and II are combined, the correlation between deficit and pay-off is $r = .55$. Corrected for attenuation, this correlation becomes $r = .79$.

The net pay-off values may also be computed using the last two minutes of recovery as a resting level, summing the measurements over the first five minutes of recovery. In this case, the correlation between deficit and pay-off is $r = .47$ for Test I and .40 for Test II. Averaging the Test I and II deficits at minute 5 and Test I and II pay-offs, results in $r = .53$ between deficit and pay-off. Corrected for attenuation, this becomes $r = .76$. All of the correlations obtained by this method are statistically significant ($r = .39$ required for significance at the 5% level).

HENRY[5] reported a correlation of $r = .79$ between $O_2$ uptake and debt pay-off $k$'s (rate constants) in his 12 subjects at the rather light work load of 15 mKg/min. Since the rate constant is one of the parameters of both the uptake deficit and debt pay-off curves, his results tend to agree with those of the present study in showing a substantial relationship between individual deficit and pay-off values. Theoretical reasons for expecting the correlation have been discussed by HENRY[5, 6].


## Summary

Twenty-six young male subjects performed work on a bicycle ergometer at a rate of 640 mKg/min. There were two tests per subject; one used a five-minute work period and the other a ten-minute work period. Oxygen uptake curves were obtained during the work and for seven minutes of recovery. Statistical analysis showed that no true steady state was reached even at this relatively low level of work. The deficit part of the average $O_2$ uptake curve was an almost exact mirror image of the repayment curve. The correlation between the individual deficit and pay-off values of oxygen uptake was found to be significant.


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