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# Effect of Thermal Stress & Workload on Oxygen Debt in Healthy Subjects

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**ABSTRACT**

The influence of thermal load on oxygen debt has been investigated. The experimental data were collected on six young healthy male subjects who were naturally acclimatised to heat. They were studied under three environmental conditions which may be classified for convenience sake as comfortable (C), hot humid (HH), and very hot humid (VHH). The subjects were given exercise on a bicycle ergometer for 6 min at 60 rpm, and their oxygen consumption was measured during rest, throughout exercise period (6 min) and for 30 min post-exercise period. The oxygen debt was determined at three different submaximal workloads of 400, 500 and 600 kgm/min (equivalent to 65, 82 and 98 W) under each environmental condition. The results indicate a significant increase in oxygen debt with increase in thermal stress ($p < .001$) as well as workload ($p < .001$). Linear regression equations have been constructed as suggestive alternative method for the prediction of oxygen debt from thermal load or/and workload.

## 1. INTRODUCTION

Oxygen debt is a measure of energy production during recovery which replenishes the anaerobic reserves depleted during exercise[1-3]. The assessment of oxygen debt is necessary and important for the calculation of total energy cost of exercise.

The oxygen debt values are reported in some studies either for a maximal physical effort or for a fixed submaximal exercise under comfortable environment[4-6]. Very often, the exercise has to be performed in hot environment as in the case of industrial and military situations. However, not much information is available about changes in the quantitative aspects of oxygen debt with increasing thermal load and workload. Besides, the conventional method for oxygen debt determination requires the experimental subject to sit for long periods of recovery, ranging from 10-15 min in some studies to about 1-1.5 h in other studies[7-8]. Also, for the whole duration of recovery, the subject has to sit while breathing through mouth piece and nose clipped, which is inconvenient to the subject. This study was undertaken (i) to provide information on the quantitative aspects of changes of oxygen debt with increasing thermal load and workload, and (ii) to suggest a suitable method of prediction of oxygen debt on the basis of regression techniques.

## 2. MATERIALS & METHODS

The studies were conducted on six healthy Indian male subjects with mean age, height and weight of 24.2 ± 2.5 years, 166.2 ± 5.3 cm and 52.7 ± 3.7 kg, respectively. The subjects were usually exposed to 22 - 44 °C ambient temperature during the year. They were also given exercise for 6 min at fixed workload of 400, 500 and 600 kg/min (equivalent to 65, 82 and 98 W) in a hot chamber under simulated environmental conditions. The thermal load of the environmental conditions were 22.7 °C, 30.3 °C and 33.6 °C in terms of Oxford index, and for convenience sake is classified as comfortable (C), hot humid (HH) and very hot humid (VHH) (Table 1).

**Table 1. Simulated environmental conditions during work**

| Thermal environment | Dry bulb temp (°C) | Wet bulb temp (°C) | Relative humidity | Oxford index W.D. (°C) |
|---|---|---|---|---|
| Comfortable | 27.0 | 22.0 | 60 | 22.7 |
| Hot humid | 37.0 | 29.0 | 60 | 30.3 |
| Very hot humid | 40.0 | 32.5 | 60 | 33.6 |

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The subjects reported to the laboratory after a light breakfast and were given rest for about one hour. Their oxygen consumption during rest ($VO_2$) was recorded for 10 min under each environmental condition. Each subject performed exercise on mechanically braked bicycle ergometer. During exercise, pedal revolutions were maintained at 60 rev/min. For measuring exercise ventilation, the subjects were made to breathe through a low resistance breathing valve (Collins) into a Cowan Parkinson dry gas meter. The fixed expired air samples were analysed for oxygen and carbon dioxide content by passing through calibrated carbon dioxide analyser (Beckman) and oxygen analyser (Servomax controls). The order of allocation of nine experimental conditions to each of the six subjects was randomised, as given in Table 2. The nine experimental conditions were investigated on different days. The oxygen consumption was measured for the entire period of exercise, i.e., 6 min under test condition and 30 min during recovery after the exercise in a comfortable room adjacent to the chamber. The oxygen debt was determined by measuring excess oxygen consumption over the resting baseline for each individual[9-10].

Table 2. Plan of experiment and order of allocation

| Subject conditions | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|
| 1 A | 4 | 1 | 9 | 7 | 3 | 5 |
| 1 B | 1 | 7 | 5 | 4 | 6 | 2 |
| 1 C | 6 | 8 | 3 | 9 | 2 | 4 |
| 2 A | 3 | 4 | 6 | 8 | 5 | 7 |
| 2 B | 9 | 5 | 1 | 2 | 8 | 3 |
| 2 C | 2 | 9 | 4 | 3 | 7 | 1 |
| 3 A | 7 | 3 | 2 | 5 | 9 | 6 |
| 3 B | 5 | 6 | 8 | 1 | 4 | 8 |
| 3 C | 8 | 2 | 7 | 6 | 1 | 9 |

1, 2, 3 Workloads 400, 500 and 600 kgm/min
A, B, C Thermal loads C, HH, and VHH
1 - 9 Rank order of the test performed by a given subject in a given experimental condition.

### 2.1 Statistical Analysis

To compare the changes in oxygen debt, the significance test was performed with the analysis of variance technique. Linear regression analysis was performed by taking oxygen debt as dependent variable (Y) and thermal stress and workload as independent variables (X). Since oxygen debt was found varying with thermal stress as well as with workload, a multiple regression equation of the form

$$Y = a + b_1X_1 + b_2X_2$$

was also fitted. The thermal stress was expressed as Oxford index[11], as in indoor conditions of a hot chamber, this index is known to reflect the stress better than other heat stress indices. The constants were tested for statistical significance of independent variables. The relevance of partial regression coefficients for significant contribution was tested by the analysis of variance technique. The significance of multiple correlation coefficient between observed and estimated oxygen debt was tested by F test.

## 3. RESULTS

The sample means and error variance of oxygen debt under different environmental conditions and workloads, together with significances, are given in Table 3. The oxygen debt at the workload of 400 kgm/min increased from 16.9 ml/kg in comfortable environment to 28.9 ml/kg and 44.8 ml/kg in HH and VHH conditions, and the changes were found statistically significant. A similar pattern was observed at the workloads of 500 and 600 kgm/min with increasing thermal stress. Differences in means of oxygen debt between different thermal stress levels at each workload as well as between workloads at each thermal stress were found to be statistically significant.

The data were also analysed for overall effect of thermal stress, workload and interactions of thermal stress and workload. The effect of thermal stress was significant ($p < .001$). The oxygen debt was also affected significantly ($p < .001$) by workload. However, the interaction was not found significant between thermal stress and workload, between subject and workload and also between subject and thermal stress. The linear simple and multiple regression equations for the prediction of oxygen debt from thermal stress and workload are shown in Table 4.

As the amount of oxygen debt was found to increase with thermal stress and workload, it seemed more appropriate to predict oxygen debt through a multivariate approach from thermal stress and workload. The combined effect of thermal load and workload on multiple regression equation has been found to be highly significant as tested by F ratio.

The square of a correlation coefficient being an estimate of the part of the variance of the dependent

**Table 3. Mean oxygen debt (ml/kg) at different workloads & different environmental conditions**

| Workload (kgm/min) | Environment C | HH | VHH | Error variance | LSD 5% | 1% | 0.1% |
|---|---|---|---|---|---|---|---|
| [illegible]00 | 16.9 | 28.9* | 44.8*** | 88.2 | 12.082 | 17.184 | 24.874 |
| [illegible]00 | 26.4 | 44.5** | 57.7*** | 52.3 | 9.304 | 13.234 | 19.155 |
| | b | a | b | | | | |
| 600 | 33.3 | 58.2 *** | 71.8*** | 55.5 | 9.580 | 13.625 | 19.722 |
| | c | c | c | | | | |
| Error variance | 69.3 | 85.2 | 44.9 | | | | |
| LSD | | | | | | | |
| 5% | 10.708 | 11.871 | 8.621 | | | | |
| 1% | 15.231 | 16.884 | 12.262 | | | | |
| 0.1% | 22.047 | 24.439 | 17.749 | | | | |

Significance levels

| between thermal loads for a given work load | between work loads for a given thermal load |
|---|---|
| * $P < 0.05$ | a-P $< 0.05$ |
| ** $P < 0.01$ | b-P $< 0.01$ |
| *** $P < 0.001$ | c-P $< 0.001$ |

**Table 4. Prediction of oxygen debt from thermal stress/workload**

| Prediction equations | Correlation coefficient | SEE | df | F | P |
|---|---|---|---|---|---|
| Y = -18.16 +0.12 (WL) | .4907 | 17.93 | (1,52) | 13.9927 | <.001 |
| Y = -41.38 + 2.90 (TH.L) | .6542 | 15.56 | (1,52) | 45.2399 | <.001 |
| Y = -102.05+0.12(WL)+2.90(TH.L) | .8274 | 12.15 | (2,51) | 55.3605 | <.001 |

Y = Predicted oxygen debt (ml/kg)
WL = Workload (kgm/min)
TH.L = Thermal load (°C, Oxford index)

variable which is explained by the variance of the independent variable or variables, it appears that, in the present set of results, the variance of oxygen debt is explained for 24 per cent by the workload alone, for 43 per cent by thermal load alone, and for 67 per cent by thermal load and workload together.

## 4. DISCUSSION

The importance of oxygen debt as a criterion of clinical significance in exercise has been shown by Burger and Noordergraaf[12]. Further, Roberts and Mortan have stressed the importance of measuring anaerobic capacity because of substantial contribution that anaerobic energy sources make to the short-term supra-maximal activity encountered in many team games. The oxygen debt values have been reported either for a maximal strenuous exercise or for a fixed submaximal exercise in comfortable condition. Roberts and Mortan[5] have summarised the oxygen debt values of various studies following maximal exercise which is in the range of 60 - 75 ml/kg in comfortable environment. Thomas *et al*[4] has reported the mean oxygen debt values around 15 ml/kg in submaximal exercises and 68 ml/kg in strenuous exercises when subjects exercised 4 - 10 min followed by recovery period of 17 - 45 min. Nag[6] has reported mean oxygen debt values around 80 ml/kg and 120 ml/kg at 40 per cent and 70 per cent of $VO_2$ max severity, respectively. The present values are thus in agreement with the studies of Thomas *et al* under comparable workload in comfortable environment. The workloads considered in the present study are those of practical concern for submaximal severity; and similarly, the thermal loads are those relevant to the industrial and military situations.

The oxygen debt has been found to increase significantly with increasing heatload and workload. The mechanism for increased oxygen debt with increase in thermal load is possibly due to the diversion of large amount of blood from the muscles to the skin for maintaining thermoregulation in hot environment. Skin blood flow of 1-2 l/min in heat has been reported in literature. The working muscles will have to work under reduced blood flow if an equivalent proportion of cardiac output is diverted to the skin resulting in the increase of anaerobic metabolism. The other possible reasons for increase in oxygen debt could be due to increased sweat gland activity, increased body temperature[13,14], and increased anaerobiosis[10] for maintaining thermoregulation.

The method of estimation of oxygen debt for light-to-moderate exercise has been simplified by Sen Gupta *et al*[15] and for moderately heavy-to-very heavy work by Dimri *et al*[16]. However, no attempt was made to verify the methods in hot environment because of the exhausting situations of thermal stress and of the need of fractional collection needed in these methods which impose additional inconvenience and stress on the subjects. Recourse has therefore been taken to construct simple and multiple linear regression equations for the prediction of oxygen debt. The mathematical approach of prediction with regression techniques is quite popular in many areas of physiology[17-20] The highly significant correlation coefficient between observed and predicted oxygen debt justifies the suitability of indirect approach. The correlation coefficient between oxygen debt and workload was found to be 0.49 and between oxygen debt and thermal stress 0.65. The multiple regression approach also stands vindicated as the multiple correlation coefficient further improves to 0.82.

Since the regression analysis has been performed on 54 observations only, the results may not be sufficient to ensure the generality of the prediction equations, though this size of data of oxygen debt is quite valuable in itself in view of time consuming experimental processes involved. The observations may be considered as independent owing to different physiological conditions of the subjects on different days, at different workloads and under different environmental conditions, and thus the data become amenable for statistical treatment[21]. It is felt that the estimation of oxygen debt from regression equation may serve as a useful guideline in the areas of work performance in industries and military situations. Thus, it could be concluded that oxygen debt increases with increasing thermal stress and workload. The regression equations constructed may serve useful purpose for the prediction of oxygen debt.

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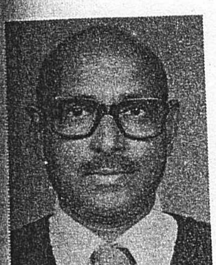
## Contributors



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