Work Speed as a Measure of an Equivalent Exercise Stress in Subjects of Different Weights

By B. van Lingen, M.D., P. D. Seaward, M.B., B.Ch., and W. A. Odendaal, D.Sc.

With the technical assistance of I. M. Kennedy

The pulse rate during and after exercise has been utilized in a number of ways to assess unfitness. The simplest method has been to measure the pulse rate at specified times after effort and to record the time taken for the pulse rate to return to the resting level. Alternatively, the pulse rate has been measured during exercise. In both instances, unfitness has been judged by the degree to which the pulse rate exceeds normal limits for a specific work load. One test procedure has been devised to assess unfitness from the work load which is required to produce a specific pulse rate. Possibly the most sophisticated tests of fitness allow an estimate of the maximum work load capacity or maximum oxygen uptake capacity.

The present study indicates that the weight of the subject has a definite influence on the pulse rate when subjects of different weights perform a constant work load. The heart rate, however, is a linear function of work speed and is shown to be independent of the body weight.

Material and Methods

Eighty-one normal adult men between the ages of 16 and 47 years (mean age 26 years) were studied. Subjects were chosen randomly from the first available applicants at the Miners’ Medical Bureau, Johannesburg (altitude 5,760 ft.). Criteria for acceptance included a normal clinical examination and radiogram of the chest. No consideration was given to previous physical training except that the subjects were ambulatory and had not suffered any illness demanding bed rest in the previous month.

Each subject was weighed without shoes or a shirt prior to the commencement of the test. At least 2 hours had elapsed since the last meal. The resting pulse rate was noted after 15 minutes of rest. The subjects were required to perform a step test at 200, 300, 400, and 500 Kg. M./min. work, which was continued for 15 minutes. The step test consisted of a single platform on which and from which he elevated and lowered himself, so that both feet were alternately on the platform and on the floor. At least 15 minutes elapsed between each work load test. Prior to the commencement of the test the subject was instructed in the performance of the test. He was allowed to steady himself by gripping a cross-bar which, however, was not to be used in assisting his stepping up and down.

The step device could be raised or lowered by means of flat boards of varying thickness to allow the step height to be adjusted to individual requirements. The step height required for a particular work load was obtained from the formula:

\[ \text{Step height (meters)} = \frac{\text{Work load (Kg. M./min.)}}{\text{Steps per minute} \times \text{body weight (Kg.)}} \]

Step heights below 25 cm. and above 35 cm. were not used, and the stepping rate was adjusted accordingly when step heights beyond these limits were required to obtain a particular work load.

The rate of stepping for each work load was controlled by a metronome which rang on every fourth beat to indicate the completion of one full step of the test. The pulse was recorded electrocardiographically during the last half minute of each exercise period, from three extremity leads of a Sanborn electrocardiograph attached to the chest at the level of the axilla. The room temperature during the tests ranged between 20 and 28 C.

Work speed in meters per minute was calculated from the work load in kilogram-meters per minute divided by the body weight in kilograms.
Table 1

Heart Rate (Beats per Minute) at Four Submaximal Work Loads (Kilogram-Meters per Minute)

<table>
<thead>
<tr>
<th></th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean heart rate</td>
<td>116.2</td>
<td>129.4</td>
<td>141.9</td>
<td>152.6</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>13.9</td>
<td>15.0</td>
<td>16.3</td>
<td>15.9</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>12.0%</td>
<td>11.6%</td>
<td>11.5%</td>
<td>10.4%</td>
</tr>
<tr>
<td>95% Confidence limits</td>
<td>±27.3</td>
<td>±29.3</td>
<td>±32.0</td>
<td>±31.2</td>
</tr>
</tbody>
</table>

Table 2

Mean Heart Rates with Standard Deviations in Three Weight Groups at Four Submaximal Work Loads

<table>
<thead>
<tr>
<th>Body weight</th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-66 Kg. (Light)</td>
<td>120.2 ± 13.7</td>
<td>136.2 ± 14.0</td>
<td>149.2 ± 16.0</td>
<td>161.1 ± 15.5</td>
</tr>
<tr>
<td>67-72 Kg. (Average)</td>
<td>114.2 ± 14.9</td>
<td>126.6 ± 13.7</td>
<td>140.3 ± 15.7</td>
<td>151.1 ± 13.1</td>
</tr>
<tr>
<td>73-104 Kg. (Heavy)</td>
<td>113.2 ± 13.0</td>
<td>123.8 ± 14.8</td>
<td>134.3 ± 14.2</td>
<td>144.5 ± 14.9</td>
</tr>
</tbody>
</table>

Results

The average pulse rate showed a linear increase with each work load, except that the average pulse rate at 500 Kg. M./min. was slightly less than that which would be expected from the pulse rates at 200, 300, and 400 Kg. M./min. work (table 1, fig. 1). It is likely that some subjects had reached their maximum pulse rate at a work load of less than 500 Kg. M./min. work, with a result that the anticipated increase in pulse rate at a work load of 500 Kg. M./min. would be less than the expected. A regression equation of heart rate (y) on work load (x) was calculated in which y = 0.12 + 92.40 ± 15.3 (fig. 1). Due to the nonlinearity of the pulse rate at 500 Kg. M./min. work a correlation ratio was calculated in preference to a correlation coefficient, and this was found to be 0.66.

The division of the subjects into three arbitrary weight groups allowed the influence of body weight on heart rate for a given work load to be assessed (table 2). The light weight group was between 50 and 66 Kg. with a mean weight of 61.9 Kg. (31 subjects). The average weight group was between 67 and 72 Kg. with a mean weight of 69.1 Kg. (24 subjects), and the heavy weight group was between 73 and 104 Kg. with a mean weight of 78.7 Kg. (27 subjects). The means of the pulse rates were consistently higher for the lighter subjects than the heavier subjects at each work load, with the average weight group falling in between (table 2, fig. 2). A family of four horizontal lines would have resulted at each work load if body weight had no influence on heart rate. As it was, all curves showed a decrease in heart rate with increasing body weight, indicating that the body weight at each work load had a

Table 3

Heart Rate as a Function of Work Load in Three Weight Groups in which y = Heart Rate (Beats per Minute) and x = Work Load (Kilogram-Meters per Minute)

<table>
<thead>
<tr>
<th>Body weight</th>
<th>Regression equations</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-66 Kg. (Light)</td>
<td>y = 0.14 x + 94.06</td>
<td>0.74</td>
</tr>
<tr>
<td>67-72 Kg. (Average)</td>
<td>y = 0.12 x + 89.43</td>
<td>0.72</td>
</tr>
<tr>
<td>73-104 Kg. (Heavy)</td>
<td>y = 0.10 x + 92.48</td>
<td>0.66</td>
</tr>
</tbody>
</table>
The average pulse rate at 200, 300, 400, and 500 Kg. M./min. work.

Regression equations relating the pulse rates and work loads in the three weight groups were calculated (table 3, fig. 3). A test of statistical significance described by Hald indicated that the regression equations obtained for the three weight groups could not be obtained by chance, and the resulting pooled t-test for the three lines was 6.50, which is significant at the 1-per cent level. The division of the subjects into three weight groups clearly indicated that the weights of the subjects had considerable effect on the pulse rate at each work load.

To eliminate the influence of weight on the pulse rate at each work load, it was considered advisable to assess the heart rate as a function of work speed in meters per minute. The latter was obtained by dividing the work load (Kg. M./min.) by the subject’s weight (Kg.). Regression equations and correlation coefficients were calculated separately for the work loads 200, 300, 400, and 500 Kg. M./min. for the dependent variable heart rate (y) and the independent variable work speed (x) (table 4, fig. 4). The test for significance showed that the four lines did not differ from each other (t = 0.21). The results indicated that the heart rate was directly related to the speed of work and was independent of the weight of the subject.

As a corollary to the above hypothesis, separate regression lines and correlation coefficients were calculated for the heart rates (y) as the dependent variable, and the work speed (x) as the independent variable, for the body weight categories previously used (table 5, fig. 5). A test of significance for
Suits of heart rate as a function of work speed at the four work loads, where

\[ y = 8.36x + 91.97 \pm 14.2 \]  (table 4)

A final regression equation was calculated from the bivariate distribution of heart rate on work speed for all observations, irrespective of work loads and body weights, where

\[ y = 8.36x + 92.0 \pm 14.2 \ (r = 0.72) \]  (fig. 6)

**Discussion**

The use of the pulse rate at or after a particular submaximal work load to assess unfitness assumes that a similar submaximal work load for subjects of different weights is an equivalent physiologic or exercise stress. The present study has shown that similar submaximal work loads produce pulse rates that are faster for light than heavy subjects, and that regression lines calculated from the pulse rates at various submaximal work loads are significantly different in light, average, and heavy weight groups. It is apparent that the pulse rate at any particular submaximal work load will be significantly affected by

**Table 4**

<table>
<thead>
<tr>
<th>Work load, Kg. M./min.</th>
<th>Regression equation</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>( y = 6.44x + 97.07 )</td>
<td>0.16</td>
</tr>
<tr>
<td>300</td>
<td>( y = 9.16x + 88.80 )</td>
<td>0.32</td>
</tr>
<tr>
<td>400</td>
<td>( y = 8.42x + 92.18 )</td>
<td>0.35</td>
</tr>
<tr>
<td>500</td>
<td>( y = 7.77x + 95.84 )</td>
<td>0.41</td>
</tr>
<tr>
<td>Pooled</td>
<td>( y = 8.36x + 91.97 )</td>
<td>0.72</td>
</tr>
</tbody>
</table>

**Table 5**

<table>
<thead>
<tr>
<th>Body weight</th>
<th>Regression equation</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-66 Kg.</td>
<td>( y = 8.40x + 92.92 )</td>
<td>0.74</td>
</tr>
<tr>
<td>(Light)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>67-72 Kg.</td>
<td>( y = 8.41x + 91.13 )</td>
<td>0.70</td>
</tr>
<tr>
<td>(Average)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>73-104 Kg.</td>
<td>( y = 7.72x + 94.23 )</td>
<td>0.63</td>
</tr>
<tr>
<td>(Heavy)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pooled</td>
<td>( y = 8.37x + 91.99 )</td>
<td>0.72</td>
</tr>
</tbody>
</table>

Heart Rate as a Function of Work Speed at Four Work Loads in which \( y = \) Heart Rate (Beats/Minute) and \( x = \) Work Speed (Meters/Minute)

Heart Rate as a Function of Work Speed in Three Weight Groups in which \( y = \) Heart Rate (Beats/Minute) and \( x = \) Work Speed (Meters/Minute)
with a large innate capacity is stressed less by a similar work load than the light subject. Where work is performed at a similar work speed the heavy subject is exposed to a heavier work load than the light subject. Despite this discrepancy in work load, both the heavy and light subjects are subjected to a similar exercise stress, relative to their innate capacities, when performing work at a similar work speed.

Absolute body weight has been used in the present study. It would appear, however, that lean body mass and the degree of fatness should be taken into consideration. The relation of pulse rate and speed of work in the light, average, and heavy weight groups showed correlation coefficients of 0.74, 0.70, and 0.63 respectively (table 5). While the particular regression lines were not shown to be statistically different, it is likely that the

the weight of the subject, and in no sense can the pulse rate at or after any particular submaximal work load be utilized to gauge unfitness, unless consideration be given to the weight of the subject.

Work speed, however, has been shown to be linearly related to the pulse rate during exercise, and this relationship is independent of the weight of the subject. It follows that meaningful interpretation of the pulse rate during exercise will be obtained when heart rate is related to work speed rather than to work load.

The relationship of the pulse rate to the work load in light and heavy subjects would appear to depend upon their physical characteristics. In heavy subjects a similar work load would be spread over a larger muscle mass, with larger hearts and lungs providing a larger oxygen uptake capacity, than it would in lighter subjects. As such, the heavy subject

Figure 4
Regression lines for heart rate (y) and work speed (x) at four submaximal work loads. A test of statistical significance showed that the regression equations did not differ from each other.

Figure 5
Regression lines for heart rate (y) and work speed (x) in the light weight group (●), the average weight group (▲), and the heavy weight group (●). A test of statistical significance showed that the regression equations did not differ from each other.
lower correlation coefficient in the heavy weight group was due to a greater degree of fatness in this group. In effect, some of the heavy weight group had a lean body mass lower than their actual weight would indicate. As such, at any particular work load they performed more work relative to their lean body mass than would lean subjects. In the light weight group it is likely that the variation of the degree of fatness was less, with a result that they showed a higher correlation between pulse rate and work speed during exercise.

A satisfactory definition of an equivalent physiologic stress would appear to be that exercise which stresses a subject an equal or equivalent proportion of his maximum capacity. The latter can be obtained by utilizing the approximately linear response between the pulse rate and work load or oxygen uptake at submaximal exercise.\(^1\)\(^-\)\(^5\), \(^10\), \(^11\) The pulse rate line at a number of different submaximal work loads is extrapolated to an average maximum pulse rate. An intercept dropped from this point will give the maximum work capacity or maximum oxygen uptake capacity when the pulse rate has been related to work load or oxygen uptake respectively. In the present study the light weight group had a higher pulse rate than the heavy weight group at each work load, and in addition they had a lower predicted maximum work load capacity (fig. 7). It follows that a similar work load in the two weight groups is not an equivalent stress, when this is related to the maximum work load capacity. However, the pulse rates for the heavy and light weight groups will be similar when any equal proportion of the maximum capacity is chosen (fig. 7). In the present study it has been shown that a similar work speed will produce a similar pulse rate response in the weight groups under consideration. It follows that exercise at similar work speeds fulfills the requirements of the definition of an equivalent physiologic stress in subjects of different weights.

Previous studies by Master and Oppenheimer\(^12\) have produced recommendations for the amount of exercise to be given in effort electrocardiography, which are at variance with those that would result from the use of speed of work as being an equivalent or proportional stress in subjects of different weights. Simonson\(^13\) has reviewed the concept of equivalent physiologic stress in detail. In regard to Master and Oppenheimer’s recommendations, he agrees that age is an important factor in physical performance. He doubts, however, “the concept of a parallelism of physiological load and body weight,” on

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**Figure 6**

A regression line with 95-per cent confidence limits for heart rate (y) and work speed (x) for all observations irrespective of work load and body weight.

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which the major part of Master and Oppenheimer's recommendations depend. In comparing the oxygen uptake during and after a two-step test, when Master and Oppenheimer's recommendations would require 18 to 29 ascents, with a step test of a constant number of ascents, Rowell and associates found a higher coefficient of variation of oxygen uptake in the Master's two-step test. In studies by Elbel and Holmer, in addition to those of Buskirk, Taylor, and Simonson, the absolute body weight had no effect on the excess pulse rates in the first and third minutes of recovery after a step test of a constant number of ascents. In the present study a similar work speed is equivalent to a constant number of steps, and this has been conclusively shown to be independent of the weight of the subject. It would appear that an equivalent physiologic or exercise stress can be obtained in individuals of different weights by subjecting them to equal work speeds. Reservations in this regard can only be made when lean body mass rather than absolute weight is considered.

The concept of a parallelism between work speed and physiologic or exercise stress can at present only be applied to normal young and middle aged men, on whom the study was made. It is likely, however, that the concept will be applicable to other normal groups, provided consideration be given to sex, age, and the degree of physical fitness.

Summary

The use of work speed, as opposed to work load, as a predictive variable for heart rate during steady state submaximal exercise, increased the correlation and decreased the standard error of the prediction around the regression line. In addition, the relationship of pulse rate and work speed was shown to be independent of body weight, while the relationship of pulse rate and work load was influenced by the body weight.

The establishment of a submaximal exercise test, which would be an equivalent physiologic stress in subjects of different weights, would require that they perform exercise at a similar work speed rather than at a constant work load. Such recommendations, in addition, are at variance with those previously made in regard to subjecting individuals of different weights to an equivalent stress.

Acknowledgment

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