THE REPRODUCIBILITY OF SUBMAXIMAL WORK HEART RATES — AN INTERIM REPORT

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ABSTRACT

Work heart rates were taken from four subjects performing standardized bouts of work on the Monark Ergometer. Whilst a linear relationship was observed between heart rate and work intensity on any one day, it is evident that day to day variations in the position (intercept) of these lines exists. The slopes are virtually identical for all subjects and for different days, however the position of the lines differs widely both between and within subjects. The best linear regression equation developed for the prediction of heart rate after 180 seconds of work from pre-exercise heart rate and work intensity was found to have 95% confidence limits of ± 12.7 beats.

Heart rates are reproducible 95% of the time to within ± 12.2 beats when pre-exercise heart rate is ignored.

INTRODUCTION

Most tests of physical work capacity (PWC) are based on a linear increase in heart rate with increasing oxygen uptake or work intensity. If the position and slope of this line can be determined from measurements made during submaximal exercise then probable values for PWC may be predicted. From previous studies in this laboratory the reproducibility of submaximal heart rate values has proved difficult, and whilst a linear relationship between heart rate and work intensity is usually found for each day, the position, i.e. the heart rate value read from the line at any particular work intensity, has shown considerable day to day variability. Clearly, any prediction of PWC from submaximal heart rate results is therefore suspect until more reproducible heart rate — work intensity graphs are obtainable.

METHOD

Standardized bouts of work were conducted using the Monark Ergometer on four, male, First Year physical education students, selected randomly. Work intensities of 100, 150, 200 and 250 Watts were performed for each day, for four days, the order of intensity being random. The order was randomized by two Latin Square designs, the purpose being to avoid the high work intensity always associated with fatigue.

Heart rate was measured by direct lead E.C.G. immediate pre-exercise (PEHR) and every 20 seconds during the 3-minute bout of work. Approximately 20 minutes was allowed between each exercise run and the whole experiment was repeated on four days — Monday 9.00 a.m., Tuesday 11.00 a.m., Thursday 9.00 a.m. and Friday 9.00 a.m. of the same week.

The experimental design was one of a statistical Latin Cube.

RESULTS AND DISCUSSION

1. Graphical presentation

Graphs from two of the subjects (Fig. 1 and 2) show

that on any one day a linear relationship exists between heart rate and work intensity, as is usually observed. The problem is that the lines are not identical, in fact on subject SG two lines were obtained which were approximately 23 beats apart! (Fig. 1). The most reproducible subject, DD gives lines approximately 15 beats apart. The slopes may be taken to be identical for all subjects and for different days, however the position of these lines differs widely both between and within subjects. This assumption of constant slope for all subjects over all days has been built into the statistical treatment.

The points on any one line were taken at least 20 minutes and up to one hour apart. During that time the subjects assisted in light experimental duties and it was anticipated that this would be sufficient to make the results statistically independent — clearly this was not the case as the results for each line are separable and not clustered about one overall line. As a 20 minute interval does not in this case give independent results, then perhaps one result per day would be independent. Since it had been arranged that each subject began each day with a different work intensity it was possible to use the first run on each day to construct a complete heart rate — work intensity graph (Fig. 3). Straight lines are no longer apparent, hence the linear relationship has been weakened.

Table I

Analysis of Variance Summary Table for heart rate results after 180 secs of work.

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	Variance Ratio	Significance %
Days	502	3	167	4.45	99
Run No.	76	3	25	0.670	NS
Subjects	12422	3	4141	110.0	99.9
W.I.	22363	3	7454	198.0	99.9
Residue	1919	51	38		
Total	37283	63			

Standard Deviation = 6.13

Table II

Analysis of Variance Summary Table for heart rate results after 120 secs of work

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	Variance Ratio	Significance %
Days	577	3	192	4.48	99
Run No.	82	3	27	0.638	NS
Subjects	10812	3	3604	83.9	99.9
W.I.	19182	3	6394	149.0	99.9
Residue	2189	51	43		
Total	32842	63			

Standard Deviation = 6.55

Fig. 1

Subject: SG.

Heart rate — Work Intensity graph for days 1, 2, 3 and 4. (Note: Day 2 results approx. 22 beats higher than Day 4).

Fig. 3

Heart rate — Work Intensity graph for Subjects DD (D), AA (A), SG (G), MS (S), for the FIRST RUN OF EACH DAY. (Note: much less definite straight lines).

Table III

Analysis of Variance Summary Table for immediate pre-exercise heart rate results.

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	Variance Ratio	Significance %
Days	1156	3	385	3.42	95
Run No.	1049	3	350	3.10	95
Subjects	7052	3	2351	20.9	99.9
W.I.	152	3	51	0.449	NS
Residue	5750	51	113		
Total	15159	63			

Standard Deviation = 10.6

Fig. 2

Subject: DD.

Heart rate — Work Intensity graph for Days 1, 2, 3 and 4. (Note: the most reproducible subject showing lines approx. 15 beats apart).

Fig. 4

Heart rate — Work Intensity graph for Subjects DD (D), AA (A), SG (G), MS (S), for the THIRD RUN OF EACH DAY. (Note: much less definite straight lines).

Let us suppose that only four results are taken on one subject. If all points are taken on the same day we would probably obtain a clear straight line, giving the appearance of a good experiment. However, had the points been taken at daily intervals we could get any of the situations shown on Figs. 3 and 4, i.e. a much less definite straight line. The former results give an illusion of accuracy whereas the latter give a much more realistic indication of the situation.

2. Statistical evaluation

(a) Latin Cube model

Table I presents an Analysis of Variance Summary Table showing the four main effects — Days, Run Number, Subjects and Work Intensity — on a Latin Cube for heart rate values taken after 180 seconds of work, based on the fundamental assumption of no interaction (discussed later under multiple regression).

An examination of the Variance Ratios (VR) reveals the following:

- i. VR (Days) of 4.451 indicates a 99% significant difference between days, i.e. on the same subjects, using the same experimental procedures and the same work intensities significantly different results are obtained on different days.
- ii. VR (Run No.) of 0.67 indicates a negligible fatigue effect during each day.
- iii. VR (Subjects) of 110 indicates a highly significant difference (99.9%) between subjects.
- iv. VR (WI) of 198 indicates a highly significant difference between work intensities confirming the assumption of no interaction is not unreasonable.

The standard deviation of 6.1 gives 95% confidence limits of ± 12.2 beats.

Corresponding Latin Cube calculations were done at the 120 seconds of work reference point and confirmed the above result, namely a 99.9% significant difference between Subjects and between Work Intensities, a 99% significant difference between Days, and a negligible training effect (VR Run No. = 0.638). The standard deviation was 6.55, hence 95% confidence limits of 13.1 beats are remarkably close to the 180 second figure. The inference would appear to be one of equivalence, the 120 second work heart rate (WHR) would seem to be as indicative as the 180 second WHR. Whilst a 2-minute exercise bout would appear to give similar exercise results, it is felt that a 3-minute bout would be less sensitive to anomalies and would therefore be preferable (Table II).

Table III confirms earlier beliefs that immediate pre-exercise heart rates (PEHR) are of little value — corresponding 95% confidence limits are ± 21 beats.

Examination of the Variance Ratios to date would indicate meaningful experimental results and that an appropriate statistical model has been used. A more detailed evaluation is warranted, for example to break down the data into Latin Squares for each Day, each Subject, each WI and each Run No.. When this was done at WHR₁₈₀ it was observed that:

- i. the standard deviation for Day 1 was 5.27, and this fell to 2.97 beats on Day 4. Either an improvement in experimental technique, or more probably, the control mechanisms of the cardiovascular system adjusting more skilfully and precisely to the work demands is suggested. This was equally apparent after only 120 seconds of work.
- ii. No pattern emerged for Run No. indicating that fatigue did not influence the residual scatter.
- iii. There would appear to be indications that the fitter subjects display a much tighter scatter of heart rate results, hence the suggestion that reproducible results would be more easily obtained on fitter subjects.
- iv. There appears to be no evidence that the higher work intensities are more reproducible than the lower ones, as previously suspected from earlier laboratory work.

(b) Multiple Correlation

The real test of this work lies in its use in predicting work heart rates from work intensity and PEHR, together with other parameters. The approach would be to use PEHR, WI, Run No., Day No., and to introduce 'dummy' variables for 3 out of the 4 subjects. Using the assumption that the graphs of all subjects show the same slope, the equation for Subject MS was found to be: $WHR_{180} = 84.7 + 0.190(PEHR) + 0.055(WI) + 0.356(Run\ No.) - 0.061(Day\ No.) \pm 12.9$. For different subjects the equation remains the same apart from the intercept value, e.g. for Subject SG the intercept is 53.2. The usefulness of this method is that a work heart rate reproducibility of ± 12.9 beats is attainable, that a small Run No. coefficient indicates a negligible fatigue effect and a very small, negative Day No. coefficient indicates a negligible training effect. Similar calculations were made at the 120 seconds of work reference point and these conclusions were supported.

It was interesting to note that the deviations of the observed results from the predicted equations at WHR₁₈₀ and WHR₁₂₀ were in fact highly correlated. ($r = 0.76$, $dF = 54$, significance in excess of 99.9%). As these deviations ought to be random and totally uncorrelated, this shows that the readings taken after 120 and 180 seconds of work are not independent results. There would, therefore, appear little value in taking more than one reference per run for predictive fitness studies.

As the Run No. (fatigue effect) and Day No. (training effect) were statistically insignificant a new equation was

calculated in terms of PEHR, WI and a 'dummy' variable for each subject, giving for example, for Subject MS: $WHR_{180} = 84.8 + 0.199(PEHR) + 0.055(WI) \pm 12.7$. The interaction between Subjects and Days was found to be highly significant (99.9%) which means that any given subject will show significant day to day variations in work heart rates. When the correction for this interaction was incorporated in the regression calculation, the confidence limits fell from ± 12.7 to ± 8.7 beats.

Why should a subject's work heart rate vary so much from day to day? This considerable variation has been observed at all levels of work intensity, yet the variation is systematic, i.e. the slopes are the same but with different intercepts (10 beats high or low at 100 Watts will be 10 beats high or low at 250 Watts). Other parameters are now being studied in an attempt to explain these day to day variations and thereby eliminate the 'dummy' variable.