REPORT APRE No. 25/77



# HEARTRATE RESPONSE TO A SINGLE SUBMAXIMAL WORKLOAD (ASTRAND'S TEST) AS AN ESTIMATE OF MAXIMAL OXYGEN UPTAKE IN BRITISH SERVICEMEN

by

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## EXECUTIVE SUMMARY

Maximal oxygen uptake is a physiological measure which has been found to be particularly relevant to ability to perform strenuous work for intermediate periods of, say, an hour. This is characteristic of military activity, and, besides being the main assessment of the Army physical fitness test, has been a major topic in APRE's physical fitness research programme.

Direct measurement of maximal oxygen uptake is a laboratory technique requiring specialised staff and equipment. For this reason predictive tests have been devised where the heartrate response to a workload of approximately half maximal is measured. One such test, devised by Åstrand, has been used in many laboratories and also in much of APRE's work, including a cross-sectional physical fitness survey of the Army, where over 3000 men were seen.

Little data was available on the accuracy of the test as applied to British servicemen, so the opportunity was taken whenever it presented itself, to obtain direct comparison between the predictive test and actually measured maximal oxygen uptake in this particular population. This report details results of this research.

The test, as compared with maximal exercise in uphill treadmill running, was found to correlate well, with a standard error of estimate of 4.8 ml/(kg min), about 10% of the mean for the group. The test overestimated fitness of fit men and underestimated that of unfit men. The correction equation was:

$$y = 34.93 + 0.340\ x$$

where y was measured maximal oxygen uptake, and x was estimated maximal oxygen uptake. Accuracy of the Åstrand test was judged sufficient for the population studies, but it could not be recommended for use in individual cases where an absolute measure was required, nor for use on very fit groups such as competition skiers. Repeatability of the test was better

than accuracy, and so the method could be used for comparative studies on the same men.

Using the fitness survey data, diurnal effects were shown to be of little practical importance, and 2 computer programs devised to avoid the original manual calculations were shown to introduce negligible error.

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## SUMMARY

Accuracy of the 6 min cycle ergometer predictive test, as practised at APRE, was compared with actual maximal oxygen uptake by uphill treadmill running using 165 servicemen subjects. Standard error of estimate of the regression between the 2 sets of results was 4.8 ml/(kg min), about 10% of the mean. Similar accuracy was found in comparing the submaximal test with maximal ergometer cycling. Accuracy was not improved by using submaximal $\dot{V}O_2$ rather than workload data in reading Åstrand's Nomogram.

The submaximal predictive test was however less accurate for a group of competition skiers. Repeatability of the submaximal test was considered adequate since it gave smaller standard deviation of differences than did the comparison of submaximal and maximal tests. Diurnal effects were shown to be of little practical importance, and 2 computer programs which avoid manual use of the nomogram were shown to introduce negligible error.

The test, with the derived regression equation, is confirmed as being of sufficient accuracy for use in population studies of British servicemen, but is not recommended for examination of individual work capacity, or for tests on very fit groups such as competition skiers.



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## CONTENTS

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## INTRODUCTION

1. Physical performance can be considered physiologically in three categories, which are distinguished by the relative importance of certain attributes. These are summarised in Table 1.

TABLE 1 Categories of physical performance

| Time Scale | Physiological attributes contributing most to performance |
|---|---|
| Brief intense effort | Muscle mass<br>High energy phosphate stores<br>Anaerobic energy production |
| Strenuous effort for periods up to 1 hour | Oxygen transport and utilisation<br>Muscle mass<br>Cardio pulmonary efficiency<br>Mechanical efficiency |
| Hard work for several hours | Energy substrate supply and availability<br>Oxygen transport |

2. It is generally held that the second item in the table best describes military activities. It is to this area, and in particular the measurement of maximal oxygen uptake (max $\dot{V}O_2$) that the main part of APRE's physical fitness research programme has been directed.

3. Direct measurement of max $\dot{V}O_2$ is a laboratory technique requiring specialised staff and equipment. There was therefore considerable interest in methods of predicting max $\dot{V}O_2$ by tests which were quicker, simpler and safer for the participants.

4. One such test, in which the heartrate response to a workload of approximately half maximal is measured, has been described in detail by Åstrand and Rodahl (1970). Predicted maximal oxygen uptake is obtained by reference to a nomogram constructed by Åstrand and Ryhming (1954), from empirical data. This test was of particular interest as it had been widely used by physiologists. Their findings have been reviewed by Åstrand and Rodahl (1970). Furthermore test results were available from several military populations, including the APRE cross-sectional survey of the British Army (Amor 1975).

5. During recent laboratory and field experiments it has been possible to examine the accuracy and repeatability of this test procedure as carried out at APRE, using British servicemen subjects. This report presents an analysis of this data, and examines 2 calculation methods which avoid manual use of the nomogram.

## METHODS

6. Data was collected during 7 studies between 1972 and 1976 (Table 2). In 5 of these trials the subjects were British servicemen without specialised physical fitness training. In the other 2, serials 3 and 5, subjects were young male competition skiers, the majority of the serial 5 subjects being soldiers. Data from these 7 groups comprised results from a total of 289 men.

7. In examining calculation methods and diurnal effects, results from 2 further groups of 121 and 316 men were extracted from the 3171 sets of data collected on the APRE 1972-3 survey of physical fitness in the British Army.

### The submaximal test

8. Subjects were weighed in PT shorts to 0.1kg and fitted with self-adhesive chest electrodes for ecg determination of heartrate. They rode for 6 min on cycle ergometers which were set initially to 750 kpm/min (123W). During the first 2 min the load was adjusted so that heartrate in the 6th minute would be between 120 and 170 beats/min. No further adjustment was allowed after 2 min. Four cycles of similar design (1 Monark and 3 Bodyguard), using friction braking (von Dobeln, 1954) were used for studies 2 to 7, but for study 1, 2 magnetically braked cycles (Muller 1952) were employed. In all the submaximal tests the subjects pedalled at 50 rev/min, paced by a metronome, and saddles were adjusted for full knee extension. Except for study 1, the cycles were calibrated using a dynamometer (Amor and Savill 1973). In the earlier experiment, conducted before the dynamometer had been built, the cycles were standardised using oxygen uptake measurement on 6 subjects.

TABLE 2 Validation tests - Estimated max $\dot{V}O_2$, cycle ergometer

| Serial | Date | Study | No seen | Procedure for actual max $VO_2$ | 6 min cycle test | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Observed | | | No of tests |
| 1 | Apr 1972 | Heat Acclimatisation trial* | 40 | cycle | HR | load | $\dot{V}O_2$ | 1 |
| 2 | Mar 1974 | APRE Field Trials Section | 16 | - | HR | load | - | 4 |
| 3 | Jul 1974 | British Men's Downhill Ski team | 12 | treadmill | HR | load | - | 1 |
| 4 | Apr 1975 | Royal Navy Field Gun Teams* | 107 | treadmill | HR | load | - | 1 |
| 5 | 1975-76 | British Biathlon Team | 30 | treadmill | HR | load | - | 1 |
| 6 | Mar 1976 | Catterick Garrison sample | 49 | treadmill | HR | load | $\dot{V}O_2$ | 2 |
| 7 | May 1976 | Continuous Operations trial* | 35 | - | HR | load | - | 2 |

*in serials 1, 4 and 7, only pre-trial data was used for the present study.

9. During some of the submaximal tests expired air was collected during the 6th minute using an Otis-McKerrow respiratory valve and Douglas bag. This was subsequently analysed for oxygen and carbon dioxide to allow calculation of oxygen uptake while cycling.

10. Heartrate was determined as the mean of 2 counts at the beginning and end of the 6th minute. Åstrand and Ryhming's nomogram, and Åstrand's age correction data were used to predict max $\dot{V}O_2$ from heartrate and either calibrated cycle load or measured oxygen uptake.

11. Repeat tests were performed within 1½ hours on study 6 and at the same time of day on consecutive days on study 7. On study 2 four tests were performed, at 0900 and 1400 on 2 days.

<u>The maximal test</u>

12. Determination of maximal oxygen uptake was undertaken on a motor driven treadmill for all cases except trial 1, where the cycle ergometer was used.

Experiments were performed either in the laboratory or in a laboratory trailer specially fitted for this work. The procedure was similar in either case. Following an initial estimate of max $\dot{V}O_2$ by the cycle ergometer the subject warmed-up for about 5 min by running at a comfortable pace on the treadmill, during which time his cycle ergometer test result was calculated while a second subject was tested on the cycle. This warm-up period also served to familiarise the subject with treadmill running, while the experimenter checked the ecg equipment and talked with him. He then rested while the second man warmed-up. The pair of subjects then alternately ran uphill on the treadmill for 3 to 4 min periods at 8 to 15 km/hr. During the final 30 to 60s, collection of ecg trace, total expired air and an inspired air sample was made. The procedure of Åstrand and Rodahl (1970) was used to select initial treadmill load at some 80% of predicted max $\dot{V}O_2$ and loads were increased by $1\frac{1}{2}$ degrees gradient (about 20% of $\dot{V}O_2$) per run. Subjects usually ran 3 to 5 loads, the final one being plainly maximal as indicated by exhaustion, pallor or hyper-ventilation.

13. Oxygen and carbon dioxide analysis of the air samples was made by paramagnetic and infra red analysers, which were standardised using cylinder gas mixtures which had been made up in the laboratory and analysed by the Lloyd-Haldane procedure. Oxygen uptake was calculated on a desk computer assuming equal volumes of inspired and expired nitrogen. Maximal oxygen uptake was assessed using as criterion a levelling or decrease of oxygen consumption as load increased. Confirmatory criteria were increased respiratory quotient, and heartrate near age-predicted maximum. In study 6 blood samples were taken after each run from an indwelling venous catheter at the forearm, and maximal exercise was also confirmed by high lactate concentrations post-exercise. These results are to be reported elsewhere.

<u>Calculation methods</u>

14. In these studies maximal $\dot{V}O_2$ was determined by hand from a 3 x enlarged copy of Åstrand's revised (1960) nomogram, as given by Åstrand and Rodahl (1970), and modified by an age correction factor (CF) derived from a regression of CF on age. This had been calculated using the factors given by Åstrand (1960) for the age range 15-60 years.

15. For handling large quantities of data, as collected in Survey work an automatic method of applying the nomogram is required. The technique used in the APRE physical fitness survey computer program was to store a matrix of mean nomogram results. These had been obtained by 5 technicians who read the nomogram for all heartrates between 120 and 170 beats/min and 5 workloads between 600 and 1200 kpm/min. Mean heartrate correction factors based on cycle calibration data were deduced by reading the nomogram for selected combinations of high and low heartrates and loads, and these together with the age correction equation were applied to the nomogram result to derive an estimated maximal oxygen uptake.

16. An alternative numerical method devised by Shephard (1970) for use on the Olivetti 101 programmable calculator was also evaluated against the above. It used an equation intended to describe Åstrand's empirically derived nomogram.

17. To test these 2 numerical methods, results from a group of 316 soldiers seen on the APRE physical fitness survey were selected from the total survey

data. These data were from men who had ridden on one cycle over a period during which 4 cycle calibration corrections had been applied. Maximal $\dot{V}O_2$ was determined from the original readings by 2 observers using the manual method and also by the 2 numerical methods.

18. Details of the numerical methods and a copy of Åstrand's nomogram are given in Annex A for reference purposes.

## RESULTS

### General

19. A number of aspects of the cycle ergometer/nomogram method for estimated max $\dot{V}O_2$ could be investigated from the data. This report has not attempted to examine theoretical aspects governing the construction of the nomogram, as these are not relevant to the main theme. As Åstrand (1960) pointed out, the method was intended to empirically relate submaximal heartrate and maximal $\dot{V}O_2$. The results given here therefore examine the accuracy and repeatability of the predicted maximal oxygen uptake as obtained by APRE. Other aspects of the use of the method which have been examined are diurnal effects, numerical solution of the nomogram, and the relative accuracy of max $\dot{V}O_2$ determination by the 2 alternatives offered by the nomogram, viz: estimation from cycle load setting or measured oxygen uptake during cycling.

20. In Table 2, 7 subject groups are specified, and these are referred to in Table 3, which summarises the calculations carried out in the present study. Serials 8 and 9 refer to the 2 blocks of results extracted from the physical fitness survey data.

The number of subjects included in the various calculations varies due to missing data, for example in serial 1, 40 submaximal heartrates were obtained, but only 39 submaximal oxygen uptakes. Similarly in serial 6, 49 initial estimates were obtained, but only 44 repeats.

TABLE 3 Summary of data analysis

| Comparisons | Serials (Table 2) | No of Subjects |
|---|---|---|
| Prediction from workload or oxygen uptake | 1, 6 | 88 |
| Prediction from workload and max test on cycle | 1 | 40 |
| Prediction from workload and max test on treadmill | 3, 5<br>4, 6 | 42<br>156 |
| Prediction from workload, initial and second tests | 2, 6, 7 | 95 |
| Prediction from workload, morning and afternoon tests | 2<br>8 | 16<br>121 |
| Prediction from workload, manual and numerical methods | 9 | 316 |

Description of subjects

21. Means and SDs of ages, heights and weights of each group of subjects are given in Table 4. Serials 6, 8 and 9 were cross-sectional samples of the Army. The other groups were not markedly different from these, except group 3, the Alpine skiers, who were a little younger.

TABLE 4 Physical description of subjects

| Serial | No of subjects | Age yr | | Height cm | | Weight kg | |
|---|---|---|---|---|---|---|---|
| | | mean | SD | mean | SD | mean | SD |
| 1 | 40 | 22.5 | 5.03 | 175.6 | 6.67 | 71.0 | 11.86 |
| 2 | 16 | 24.7 | 2.72 | 175.9 | 6.99 | 71.6 | 10.60 |
| 3 | 12 | 17.6 | 1.27 | 174.9 | 6.46 | 66.0 | 9.09 |
| 4 | 107 | 25.5 | 3.74 | 177.4 | 6.46 | 79.5 | 7.77 |
| 5 | 30 | 21.1 | 4.13 | 175.5 | 6.09 | 67.7 | 6.62 |
| 6 | 49 | 23.0 | 5.09 | 174.8 | 8.59 | 72.1 | 13.02 |
| 7 | 35 | 21.1 | 3.80 | 175.7 | 6.76 | 71.7 | 6.95 |
| 8 | 121 | 24.4 | 5.02 | 172.6 | 6.76 | 69.9 | 10.09 |
| 9 | 316 | 24.4 | 4.66 | 173.3 | 6.56 | 71.4 | 10.13 |

Estimated max $\dot{V}O_2$ and direct (cycle) max $\dot{V}O_2$

22. Forty subjects of group 1 had a mean estimated max $\dot{V}O_2$ of 43.2 ml/(kg min) with SD of 7.85 ml/(kg min). Actually determined maximal oxygen uptake on the bicycle was 42.9 ml/(kg/min) with SD 5.77 ml/(kg min). Mean and SD of differences between measured and predicted max $\dot{V}O_2$ was 0.29 (SD 2.87) ml/(kg min). This was not significant on paired t-test (t = 0.386). The regression line of y = measured max $\dot{V}O_2$ on x = estimated max $\dot{V}O_2$ was

$$y = 22.70 + 0.466\,x \qquad r = 0.634$$

This had a standard error of estimate of 4.5 ml/(kg min). Figure 1 plots the relation between estimated and measured max $\dot{V}O_2$.

Estimated max $\dot{V}O_2$ and direct (treadmill) max $\dot{V}O_2$ - Servicemen

23. Data from 156 subjects contributed to an analysis of the relation between max $\dot{V}O_2$ as predicted from cycle test, and as actually measured during treadmill running. These were 107 men of the 3 Royal Navy Field Guns teams, and 49 men selected from a randomly sampled survey of Catterick

## Measured and estimated maximal oxygen uptake cycle ergometer

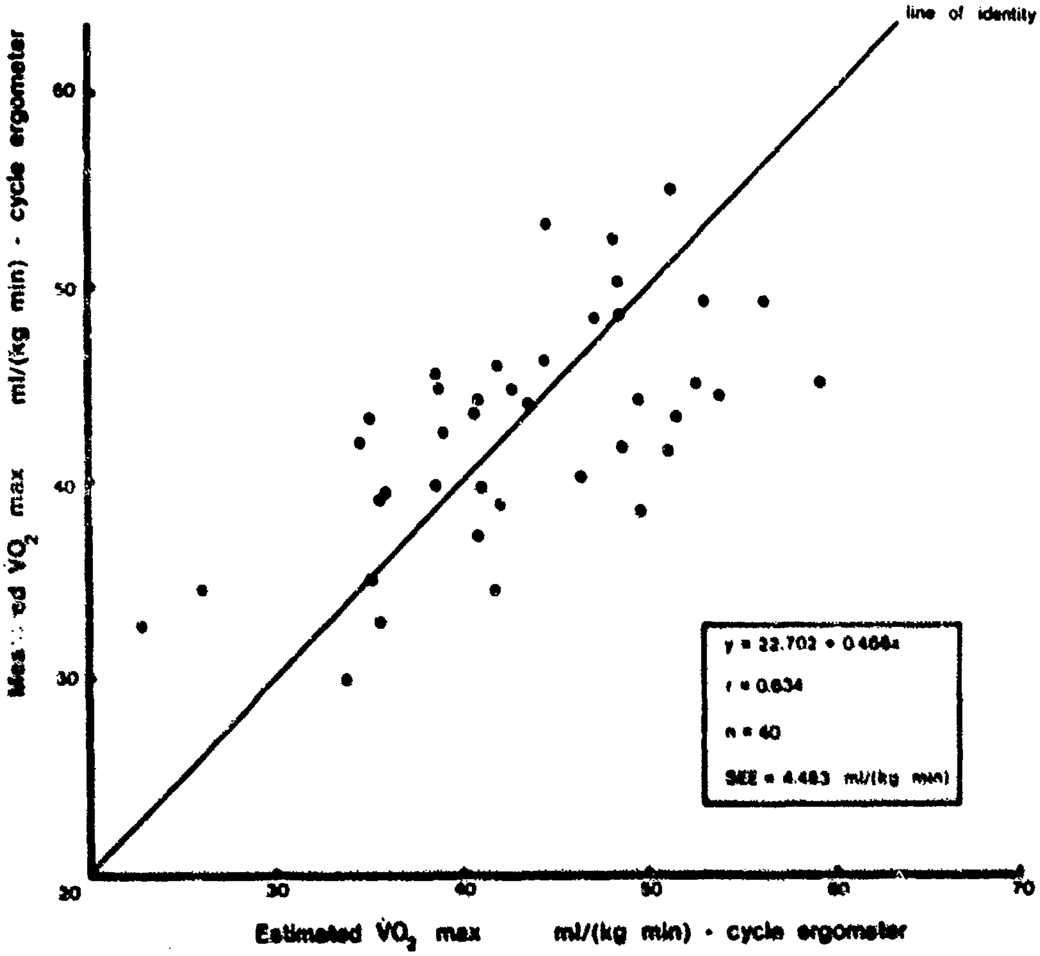



FIGURE 1

Garrison. Selection was made from results of the Army Physical Fitness Assessment, and it was intended to obtain approximately equal numbers of men throughout the fitness range. In the case of the Field Gun teams, measured at the beginning of the season, a wide range of men were also seen. Some had had little opportunity to train whereas others, shore based, were already well trained.

24. Where repeat tests were made (see Table 2) the initial tests were used for this analysis. Mean measured and estimated max $\dot{V}O_2$, in ml/kg(min) were

| | | | |
|---|---|---|---|
| measured mean | 52.6 | SD | 5.95 |
| estimated mean | 52.0 | SD | 10.17 |

Mean difference was 0.62 ml/(kg min) and SD of differences was 8.30 ml/(kg min). Correlation of error (defined as estimated max $\dot{V}O_2$ minus measured max $\dot{V}O_2$) with measured max $\dot{V}O_2$ was 0.0037. The regression line (Figure 2) of y = measured max $\dot{V}O_2$ and x = estimated max $\dot{V}O_2$ was

$$y = 34.93 + 0.340\,x \qquad r = 0.581$$

This had a standard error of estimate of 4.8 ml/(kg min), Figure 3 shows the error in estimated max $\dot{V}O_2$, related to measured max $\dot{V}O_2$.

Estimated max $\dot{V}O_2$ and measured (treadmill) max $\dot{V}O_2$ - Athletes

25. Data was available from 2 groups of skiers competing at international level, 12 young men of the British Mens Downhill Team, and 30 members of the British Biathlon Team. The majority of the Biathletes had been tested several times in successive seasons. The Alpine skiers were newcomers to the laboratory, and generally younger, but being well trained they rapidly adapted to treadmill running.

In the case of these men the cycle ergometer test underestimated max $\dot{V}O_2$ by a mean of 4.4 ml/(kg min), mean values in ml/(kg min) being

| | | | |
|---|---|---|---|
| measured mean | 62.2 | SD | 6.27 |
| estimated mean | 57.8 | SD | 9.42 |

SD of differences (viz estimated minus measured max $\dot{V}O_2$) was 9.89 ml/(kg min). The regression of y = measured max $\dot{V}O_2$ and x = estimated max $\dot{V}O_2$ (Figure 4) was

$$y = 52.38 + 0.170\,x \qquad r = 0.256$$

Correlation was quite low, and standard error of estimate was 6.1 ml/(kg min).

Duplicated tests - estimated max $\dot{V}O_2$

26. In three studies a total of 95 men were tested twice. In two of those 44 men at Catterick, and 16 men of the APRE Field Trials Section

## Measured and estimated maximal oxygen uptake British servicemen

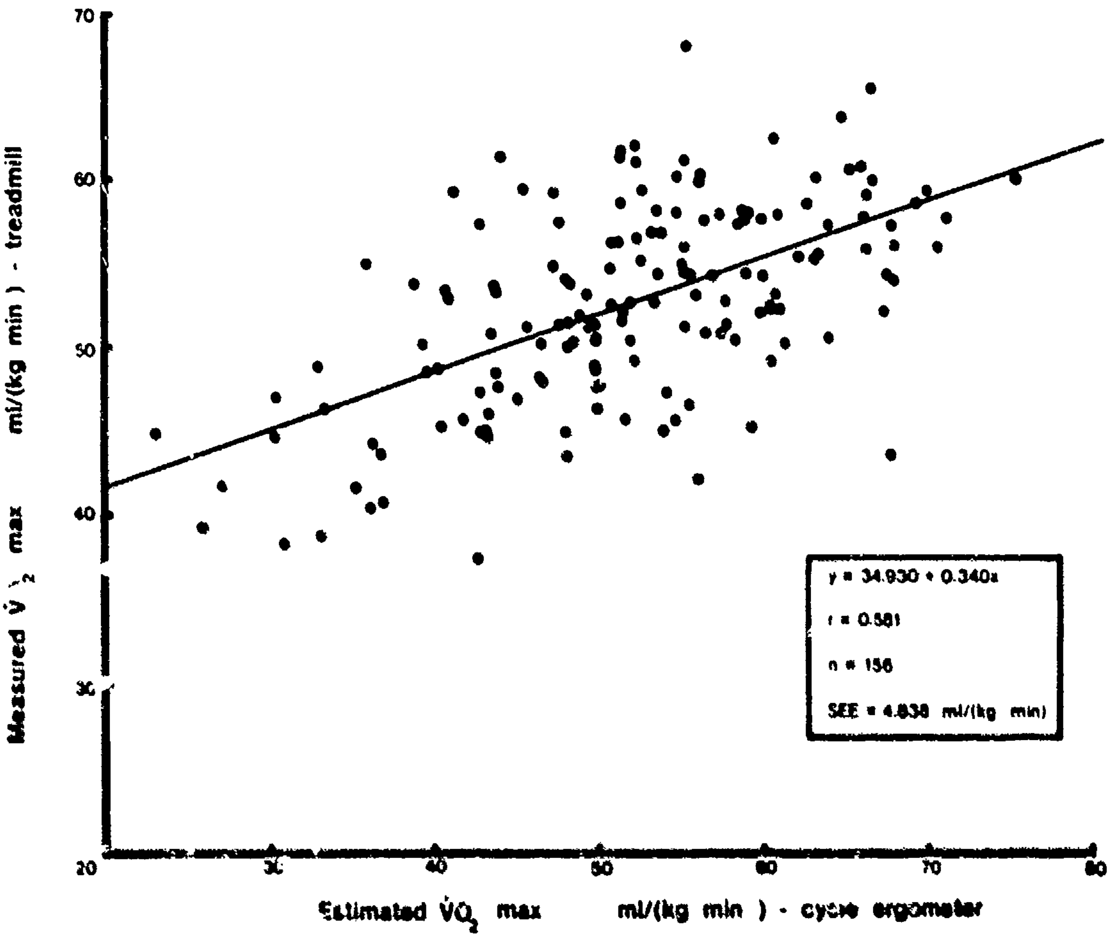



FIGURE 2

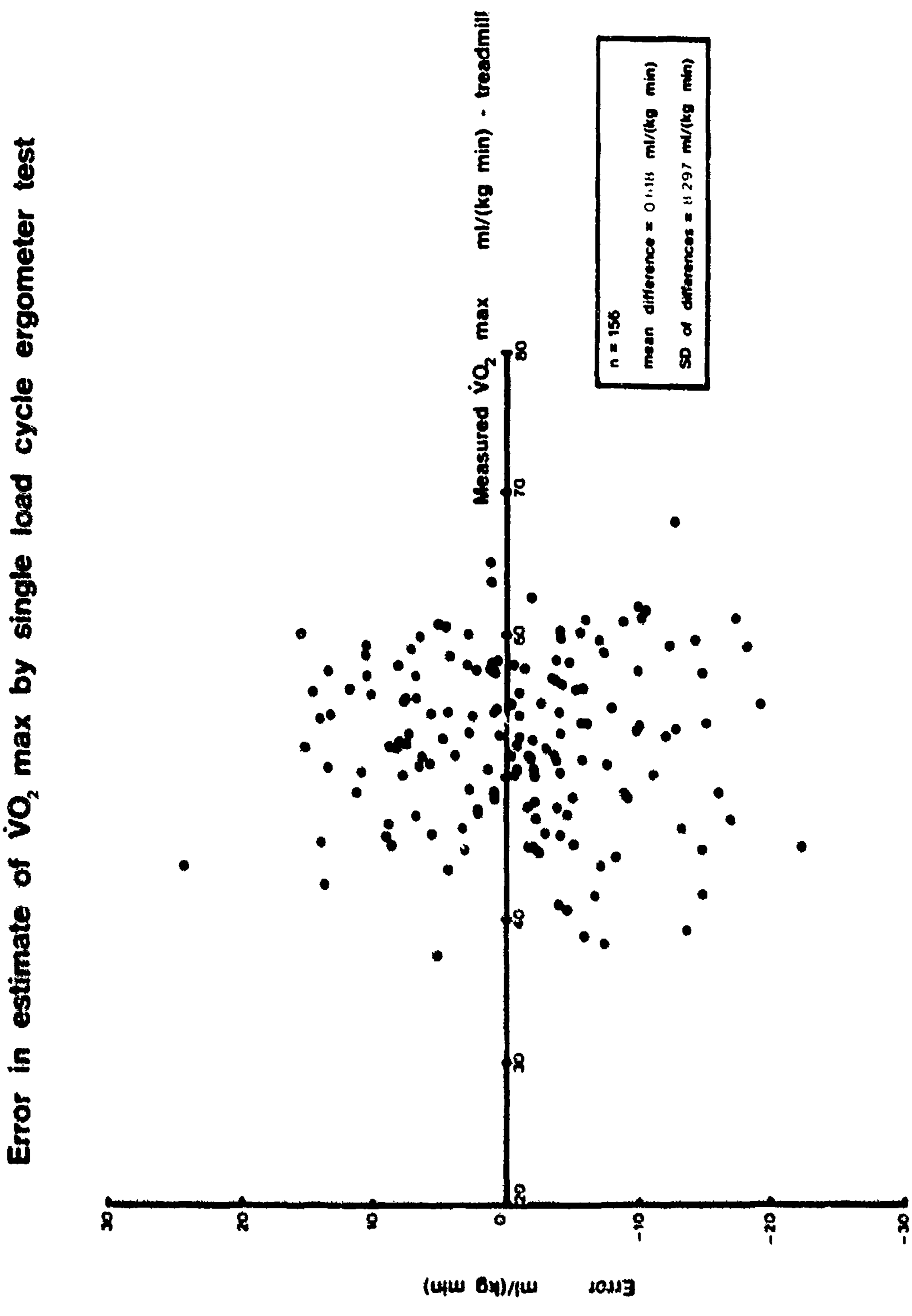

Error in estimate of $\dot{V}O_2$ max by single load cycle ergometer test
Measured $\dot{V}O_2$ max ml/(kg min) - treadmill
Error ml/(kg min)
n = 156
mean difference = ml/(kg min)
SD of differences = ml/(kg min)
20
30
40
50
60
70
80
30
20
10
0
-10
-20
-30

FIGURE 3

## Measured and estimated maximal oxygen uptake athletes

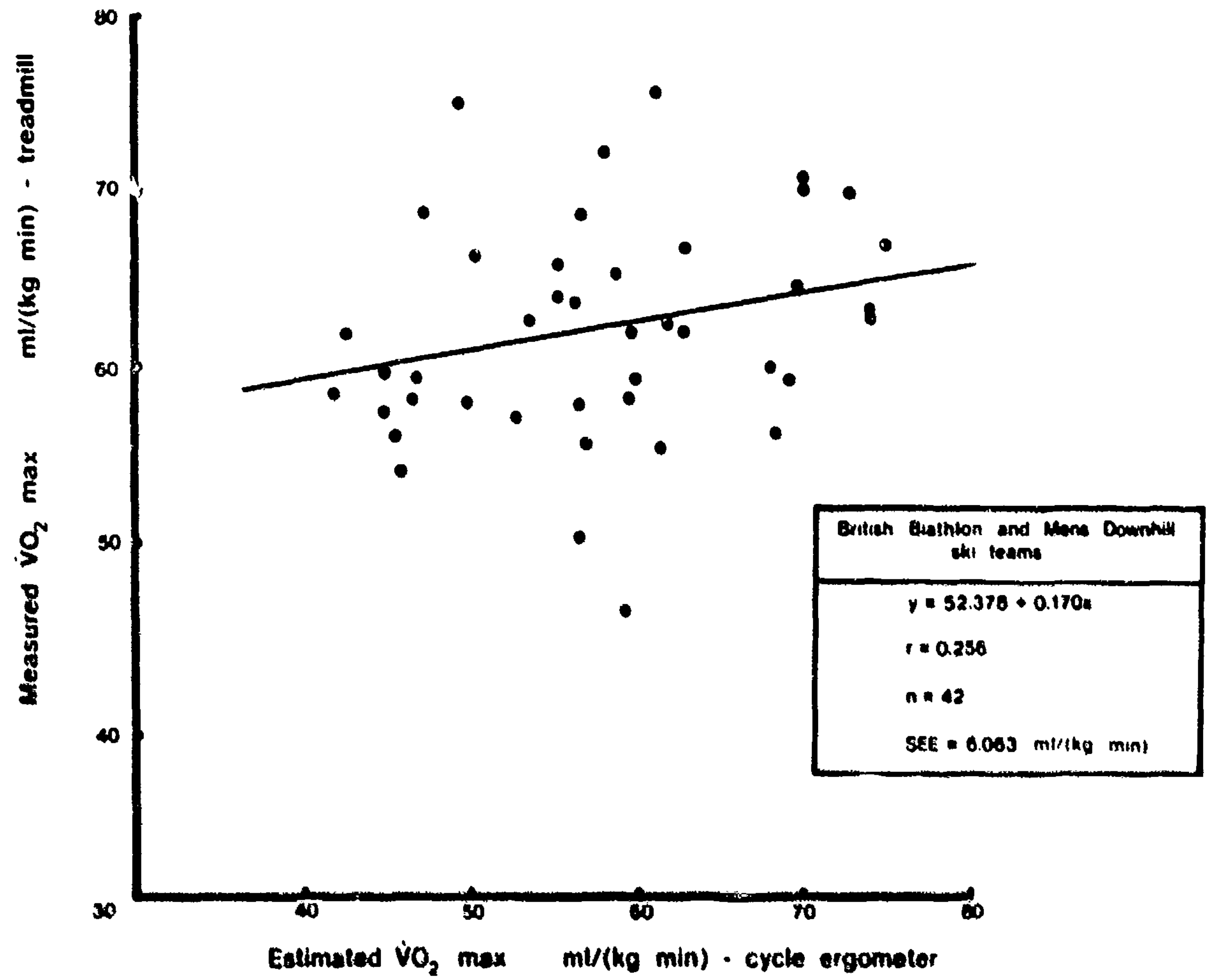



FIGURE 4

were tested within $1\frac{1}{2}$ hours in the laboratory. A further 35 men on the continuous-operations trial visited the laboratory twice at the same hour on two consecutive days during the baseline period of the trial. Apart from the 16 APRE soldiers, all the subjects were naive, ie this initial test was their first experience of a cycle ergometer protocol.

Estimated max $\dot{V}O_2$ results in ml/(kg min) for this group of 95 men were

| | | |
|---|---|---|
| first test | mean 46.9 | SD 10.03 |
| second test | mean 46.2 | SD 10.04 |

These means were not significantly different on paired t-test ($t = 1.13$), and the correlation coefficient of regression of second test on first test was 0.82. Mean difference between repeat tests was -0.71 ml/(kg min). This test-retest data is plotted in Figure 5. In Figure 6 the test-retest differences are plotted against initial test results. There was a small but not significant trend to an improved result on the second test with men of low work capacity, and vice-versa with fit men.

Estimation of max $\dot{V}O_2$ from cycle load or from submaximal $\dot{V}O_2$

28. In two experiments oxygen uptake was measured during the submaximal cycle ride. It was thus possible to compare the two methods offered by the nomogram, namely prediction from cycle load or from submaximal $VO_2$. Comparisons were made in two ways, by considering the relation between estimated and measured max $\dot{V}O_2$, or by comparing the two estimations. Since the results from the first experiment were obtained before the cycle calibration dynamometer was constructed and maximal $VO_2$ was determined by different methods it was not possible to combine the groups for the former method of comparison.

29. Estimated and measured max $\dot{V}O_2$ for these groups are given in Table 5, and Figure 7 shows the relation between the 2 methods for the 49 subjects seen on Study No 6. (Only 44 group 6 subjects contributed to Table 5 since these results were calculated from the test-retest data).

TABLE 5 Estimated max $\dot{V}O_2$ from cycle load or submax $\dot{V}O_2$

| Study | No of subjects | Measured | | Load predicted | | | | $\dot{V}O_2$ predicted | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mean | SD | mean | SD | correlation | SD diffs | mean | SD | correlation | SD diffs |
| 1 | 40 | 42.87 | 5.77 | 43.24 | 7.85 | 0.63 | 2.87 | 43.53 | 8.26 | 0.65 | 6.23 |
| 6 | 44 | 49.90 | 6.73 | 45.58 | 11.43 | 0.63 | 8.88 | 45.12 | 10.10 | 0.62 | 7.93 |

## Repeatability of estimated max oxygen uptake
## Åstrand's nomogram method

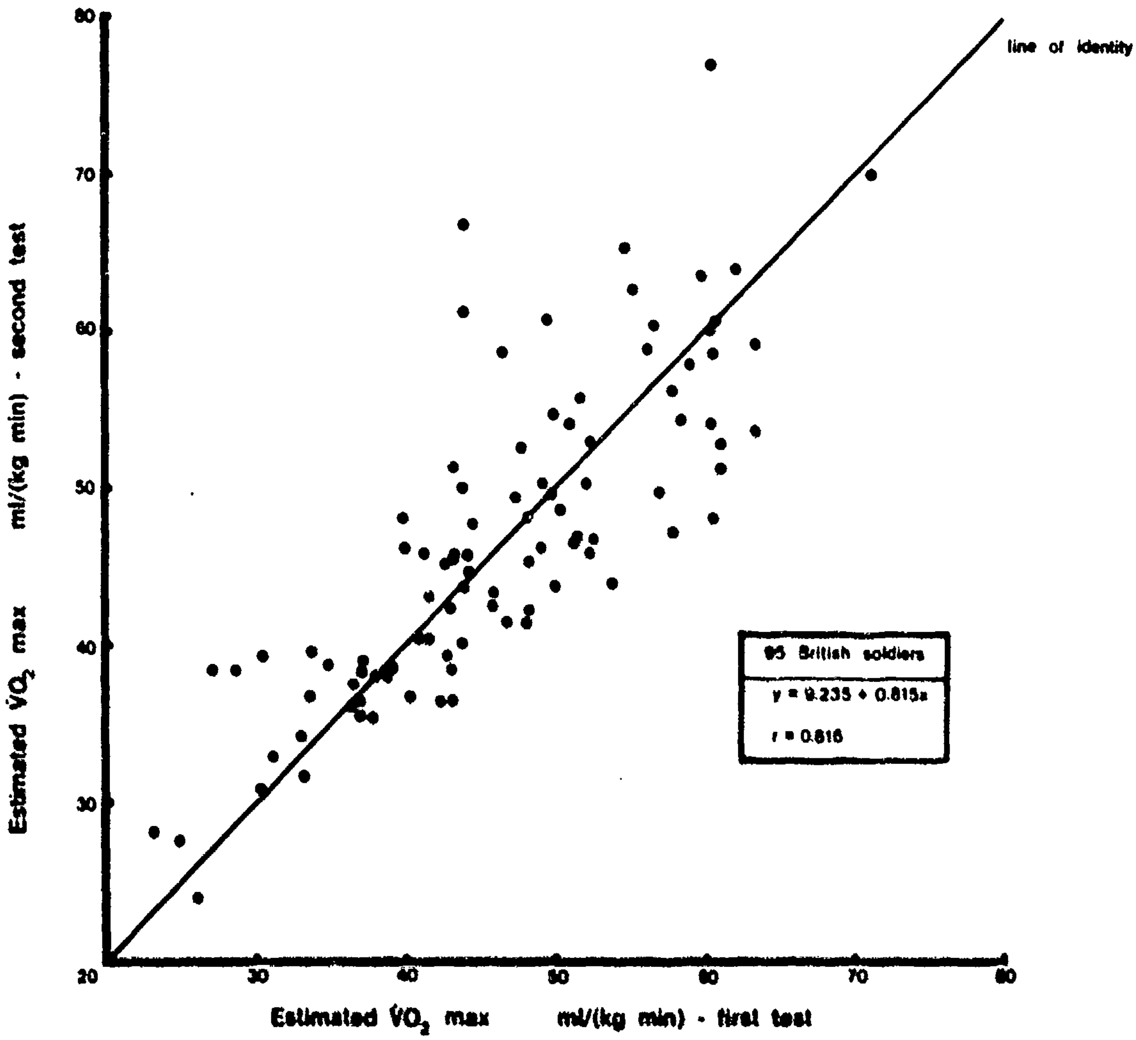
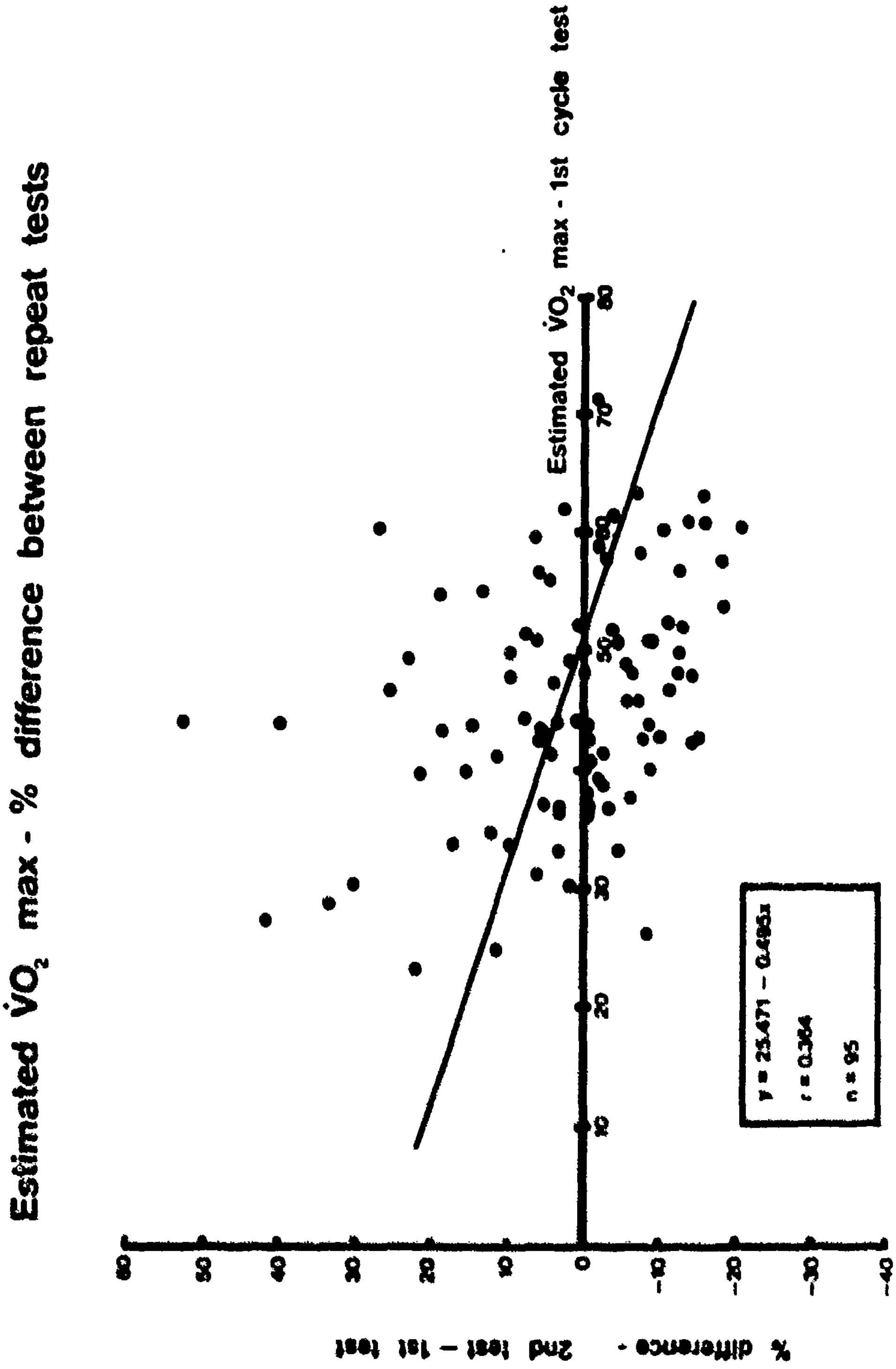
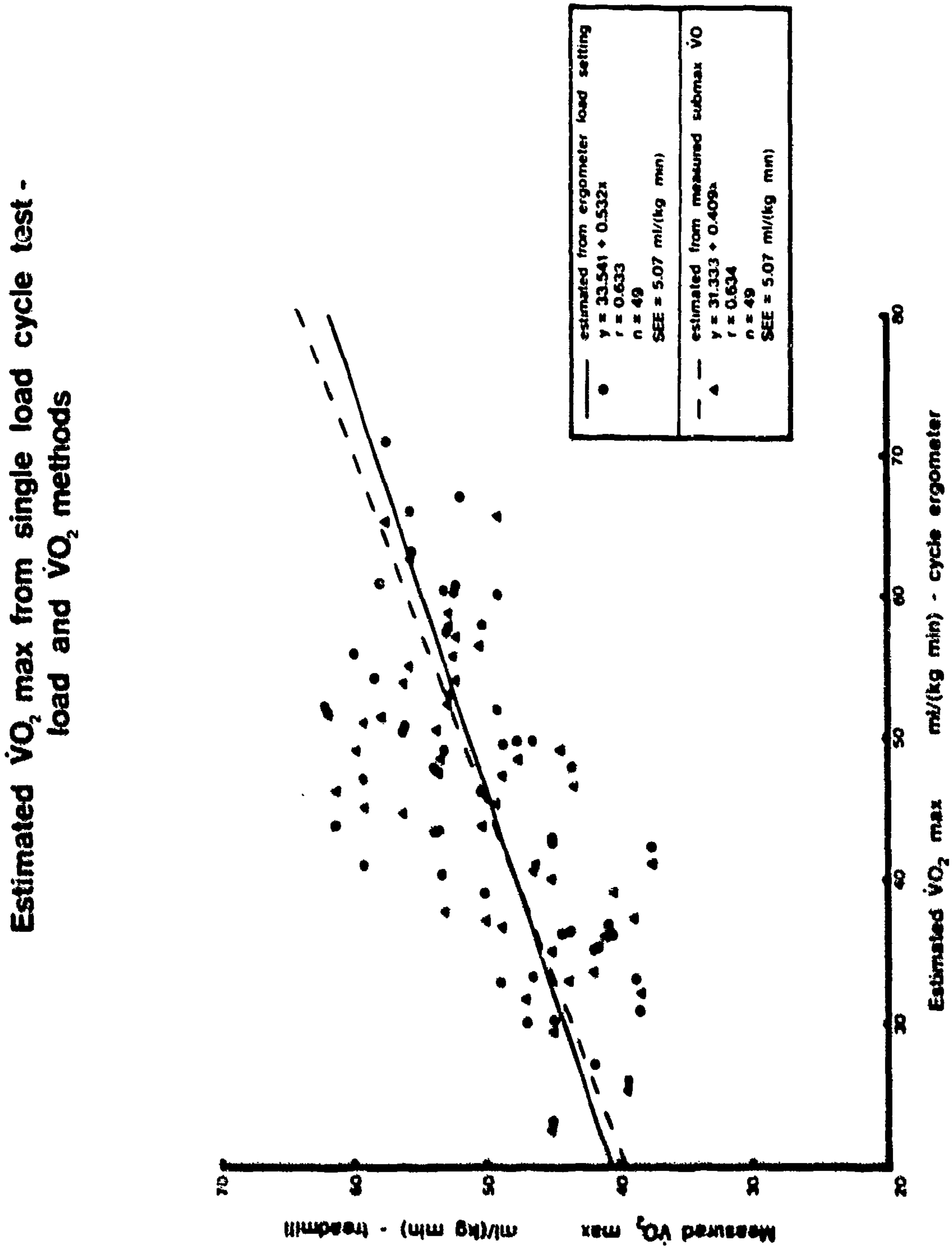



FIGURE 5



Estimated $\dot{V}O_2$ max - % difference between repeat tests
Estimated $\dot{V}O_2$ max - 1st cycle test
% difference - 2nd test – 1st test
y = 25.471 – 0.496x
r = 0.364
n = 95
10
20
30
40
50
60
70
80
60
50
40
30
20
10
0
–10
–20
–30
–40


FIGURE 6



Estimated V̇O2 max from single load cycle test - load and V̇O2 methods
Measured V̇O2 max ml/(kg min) - treadmill
Estimated V̇O2 max ml/(kg min) - cycle ergometer
20
30
40
50
60
70
80
estimated from ergometer load setting
y = 33.541 + 0.532x
r = 0.633
n = 49
SEE = 5.07 ml/(kg min)
estimated from measured submax V̇O
y = 31.333 + 0.409x
r = 0.634
n = 49
SEE = 5.07 ml/(kg min)


FIGURE 7

Correlation between measured and predicted max $\dot{V}O_2$ was almost the same by either method, and standard deviation of differences was similar except in the case of load-predicted, cycle maximum, where it was smaller than the other results.

30. In comparing the two estimation methods directly, the data could be combined to obtain a total of 88 subjects. The correlation between the 2 prediction methods was 0.896, somewhat higher than the individual correlation with measured max $\dot{V}O_2$ and the mean and SD of differences between the 2 methods was 0.38 (SD = 4.47) ml/(kg min) (Figure 8).

31. Forty four men in study 6 rode twice with oxygen uptake measurement. It was thus possible to examine the repeatability of the two estimation methods (Table 6).

TABLE 6 Repeatability of 2 prediction methods

| Method | No of Subjects | 1st Ride | | 2nd Ride | | Correlation coefficient | SD diffs | t |
|---|---|---|---|---|---|---|---|---|
| | | mean | SD | mean | SD | | | |
| Load | 44 | 45.58 | 11.43 | 46.67 | 11.75 | 0.79 | 7.56 | 0.96 |
| $\dot{V}O_2$ | 44 | 45.12 | 10.10 | 46.76 | 9.49 | 0.80 | 6.27 | 1.73 |

Although the second test gave a slightly higher estimate of max $\dot{V}O_2$ by either method, the differences were about the same and were not statistically significant on paired t-test. Other measures of repeatability, namely correlation coefficients and standard deviation of differences were also similar, the $\dot{V}O_2$ method being slightly superior.

Diurnal Effects

32. Diurnal fluctuation in resting heartrate is a well known phenomenon, and the possibility that a similar effect might be found in predicted max $\dot{V}O_2$ was investigated using data from groups 2 and 8. In study 2 full data from 16 men was available for the first of the morning and afternoon rides. Although the mean afternoon result was somewhat lower than the morning, it was found to be not statistically significant, on Analysis of Variance. (Table 7).

TABLE 7 Analysis of Variance of morning and afternoon predicted max $\dot{V}O_2$ - 16 subjects

| | Sum squares | df | Mean square | F ratio | Significance |
|---|---|---|---|---|---|
| Subjects | 1929.9 | 15 | 128.7 | 3.03 | 5% |
| Time | 136.5 | 1 | 136.5 | 3.21 | NS |
| Residual | 637.6 | 15 | 42.5 | | |

## Estimated $\dot{V}O_2$ max - from ergometer load setting and from measured submaximal $\dot{V}O_2$

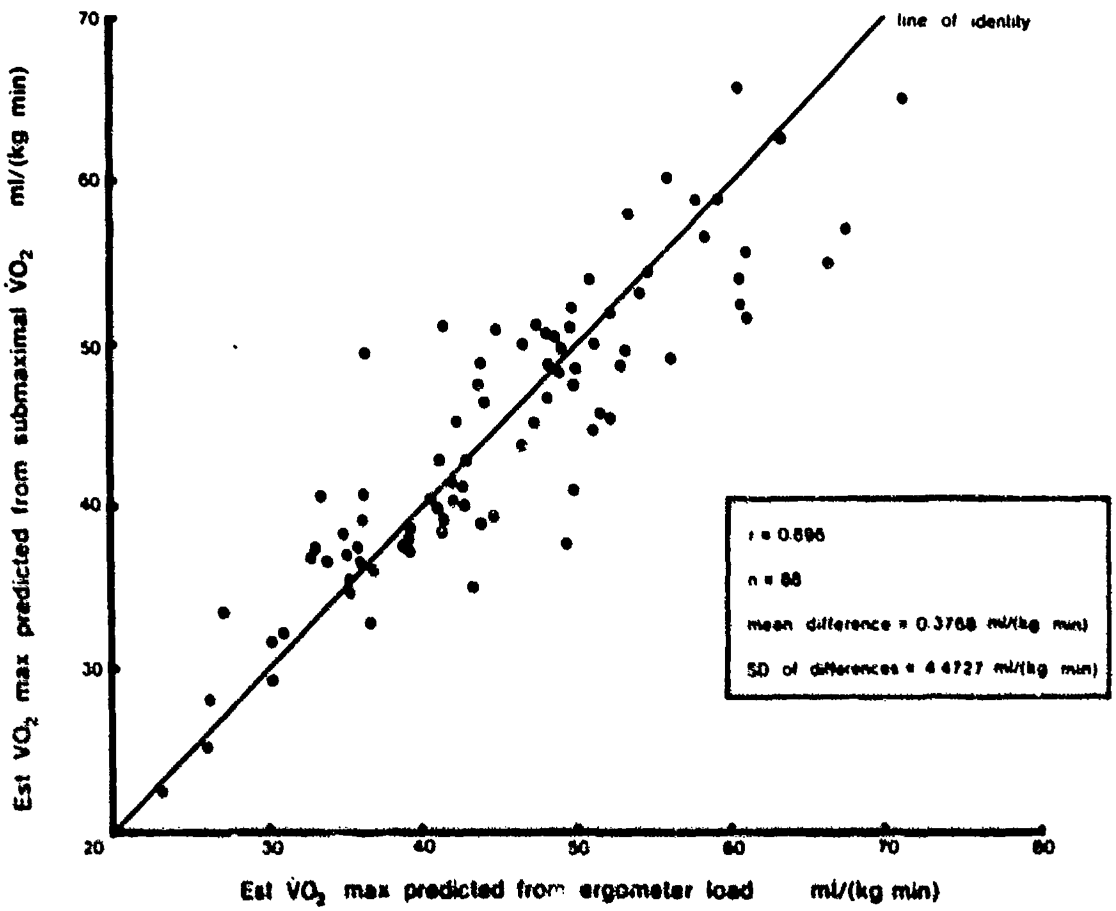



FIGURE 8

Mean and SD of morning and afternoon results, in ml/(kg min) were

| | | |
|---|---|---|
| morning | mean 48.3 | SD 10.94 |
| afternoon | mean 44.2 | SD 6.37 |

33. This difference, although not significant statistically, was of some practical importance insofar as it affected the estimation of population means, as determined in the survey of physical fitness. Data from a larger group of men was therefore selected from the 3171 sets of results recorded during the survey. These data were from the first 20 men seen each morning and each afternoon on 3 days where a total of 286 men had been tested. No known selection in attendance had been applied. These were seen from 0900 to 1000 hours, and from 1400 to 1500 hours, and totalled 121 men. Mean results, in ml/(kg min) were

| | | |
|---|---|---|
| morning (n = 61) | mean 45.0 | SD 8.60 |
| afternoon (n = 60) | mean 44.1 | SD 7.89 |

These were not significantly different on t-test (t = 0.584), but a small trend to lower results was found in the afternoon group.

Calculation methods

34. Original readings of heartrate and cycle load setting from a group of 316 men who rode one of the 4 cycle ergometers used on the physical fitness survey were selected from the survey data. This included a range of workloads from 600 to 1050 kpm/min, and covered a period over which 4 cycle calibration corrections had been applied. Estimated max $\dot{V}O_2$ was calculated by the three methods described above, the mean of 2 observer's readings being taken for the manual method.

TABLE 8 Estimated max $\dot{V}O_2$ by 3 calculation methods (n = 316)

| Method | Est max $\dot{V}O_2$ ml/(kg min) | | Difference from manual method | | |
|---|---|---|---|---|---|
| | mean | SD | mean | SD | correlation |
| Manual-nomogram | 44.58 | 8.49 | - | - | - |
| APRE survey program | 44.43 | 8.59 | -0.154 | 0.532 | 0.998 |
| Shephard program | 44.19 | 8.56 | -0.387 | 0.989 | 0.993 |

35. Mean results were not significantly different using Normal statistics, the SD of differences between the manual method and the 2 computer methods was less than 1 ml/(kg min) in either case, and correlation coefficients were similarly high. With these subjects the APRE method gave marginally better agreement with the traditional manual method than did Shephard's method.

## DISCUSSION

36. The APRE method of conducting the cycle test differed from that recommended by Åstrand and Rodahl (1970) in that the load was adjusted during the early part of the test, and so their recommendation of at least 5 min steady state work was not fully met. Furthermore the subjects used to construct the nomogram differed in nationality and age from the somewhat selected population of the British Army. These were the main reasons for making the measurements reported here.

### Accuracy

37. Mean difference between estimated and measured maximal oxygen uptake was less than 1 ml/(kg min) for groups of 40 and 156 servicemen tested by either the cycle or treadmill maximal methods, but SD of differences was larger when maximal testing was by treadmill. As the cycles used for the maximal cycle test were not the same model, nor calibrated by the same method as those used for the treadmill comparison, and different subjects were measured, it is not possible to infer that the submaximal test estimates treadmill-determined or cycle-determined max $\dot{V}O_2$ equally, and these results are not therefore necessarily in disagreement with those of other observers who have found max $\dot{V}O_2$ to be somewhat higher on treadmill running, compared to cycling.

38. Åstrand and Rodahl (1970) state the nomogram method tends to over-estimate at high max $VO_2$ and under-estimate at low values, with an SD of differences of 10 to 15% of reading. The present results on British servicemen confirm these findings and the regression of treadmill-determined max $\dot{V}O_2$ on estimated max $VO_2$ from the cycle test enables correction of max $\dot{V}O_2$ as determined by Åstrand's nomogram, with a standard error of estimate of 4.8 ml/(kg min), a little over half the error of the uncorrected cycle result. This regression line cuts the line of identity at 52.9 ml/(kg min). Since the mean measured max $VO_2$ of the group of 156 men from which this equation was determined was 52.6 ml/(kg min) it can be seen that the estimation of max $VO_2$ by nomogram is accurate for this population if only mean values are considered. In the present data the error of the nomogram method appeared to be random in nature, since there was no correlation with measured max $VO_2$ ($r = 0.0034$). Accordingly, percentage errors increase as measured max $\dot{V}O_2$ decreases, and therefore it is preferable to express error in units of measurement, rather than percentage form, unlike Åstrand's practise.

39. Results obtained from the 2 groups of skiers produced a lower correlation between measured and estimated max $VO_2$ and a larger standard deviation of differences. Although the estimated max $VO_2$ was only 4.4 ml/(kg min) low on average, (about 7% of population mean value), the low correlation suggests this method could not be reliably applied to data from these men. Moreover, in considering data from athletes it is generally individual rather than group results which are of interest, and it is in this area that the data produced by this estimated method is least reliable.

### Repeatability

40. In examining performance data from naive subjects it is sometimes suggested that a "first-time" practice effect exists. The present repeatability data does not support this view, the mean difference between

repeat data being less than 1 ml/(kg min). The standard deviation of differences between repeated measures was 6.09 ml/(kg min), a little less than the SD of differences between measured and estimated values of max $\dot{V}O_2$ which was 8.28 ml/(kg min).

Estimation from $\dot{V}O_2$ or load data

41. The two methods correlated well, and mean values were in good agreement with each other and with measured max $\dot{V}O_2$. Moreover repeatability of the two methods was about the same. One contribution to the accurate estimation of submaximal $\dot{V}O_2$ from load was individual cycle calibration. The load settings of the cycles used were found to be up to 20% in error (Amor and Savill 1973) and if this had not been corrected before applying data to the nomogram, this error would have been reflected in a consistent difference between the 2 methods.

42. Provided the cycle load settings have been calibrated there would thus be little value in the extra effort of measurement of submaximal $\dot{V}O_2$, except for subjects who are extremes of weight, obesity or fitness, where mechanical efficiency at ergometer cycling is known to be abnormal.

General

43. Although a trend to lower results in the afternoon was found in a small group ($n = 16$), the difference was not significant, and in examining survey data the differences were considerably smaller than the error of the method.

44. The 2 computerised calculation methods were shown to be useful. Neither introduced an appreciable random error, and the constant error was negligible in both cases.

## CONCLUSIONS

45. Accuracy of the single load cycle ergometer method of estimating maximal $\dot{V}O_2$, (Åstrand's test), as used by APRE with British servicemen was shown to be similar to that claimed by the originators of the method, SD of differences between estimated and measured max $\dot{V}O_2$ being 8.28 ml/(kg min). A regression line

$$y = 34.93 + 0.34\,x$$

where y is measured max $\dot{V}O_2$ and x is estimated max $\dot{V}O_2$ enabled correction for the under and over-estimate which occurred with men of low and high max $\dot{V}O_2$'s respectively, and produced a standard error of estimate of 4.8 ml/(kg min).

46. Comparative tests on 2 groups of competition skiers gave poor estimation of max $\dot{V}O_2$ by this method however.

47. Accuracy of the method was not improved significantly by measurement of submaximal $\dot{V}O_2$. Test-retest differences (repeatability) were less than the error of the method (differences between estimated and measured max $\dot{V}O_2$).

48. Diurnal effects were shown to be of little practical importance.

49. Two computer programs which avoid manual use of the nomogram were shown to introduce no appreciable error.

## RECOMMENDATIONS

50. Where a 10 to 15% random error in individual max $\dot{V}O_2$ can be tolerated, as in estimation of population mean values, the single workload submaximal cycle ergometer test is a convenient and useful tool. It cannot however be recommended as a substitute for measurement of max $\dot{V}O_2$ where individual results are required to a higher accuracy, or where tests are to be made on very fit men such as competition skiers.

51. Provided the cycle ergometers have been calibrated, measurement of submaximal $\dot{V}O_2$ of normal subjects is not recommended.

52. The two computer programs are recommended as convenient and accurate methods of avoiding manual use of the nomogram. For use with British soldiers these programs can be amended to include the correction equation relating estimated and actual (treadmill) max $\dot{V}O_2$.

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## CALCULATION METHODS

### Manual method

1. Figure 9 shows the nomogram of Åstrand and Ryhming (1954) as modified by Åstrand (1960). A straight line is drawn between the heartrate scale and a point on the left side of the combined work rate scale corresponding to either cycle load or measured submaximal $\dot{V}O_2$. The intercept with the central scale is the uncorrected estimate of max $\dot{V}O_2$ in l/min.

2. This is converted to ml/(kg min) by dividing by nude body weight, and further adjusted by multiplying by an age correction factor F. I Åstrand (1960) gave tabulated factors for ages 25 to 65 in 10 year intervals and this, as extrapolated and interpolated by Åstrand and Rodahl (1970), is given in Table 9.

TABLE 9 Nomogram correction factors for men and women

| Age, yr | Factor |
|---|---|
| 15 | 1.10 |
| 25 | 1.00 |
| 35 | 0.87 |
| 40 | 0.83 |
| 45 | 0.78 |
| 50 | 0.75 |
| 55 | 0.71 |
| 60 | 0.68 |
| 65 | 0.65 |

3. When electronic calculators are used it is more convenient to apply the age correction as a regression formula, and Table 9 reduces to

$$F = 1.2088 - 0.0090 \text{ (Age, yr)}$$

It is this formula which has been used for age correction throughout the analysis of the present data.

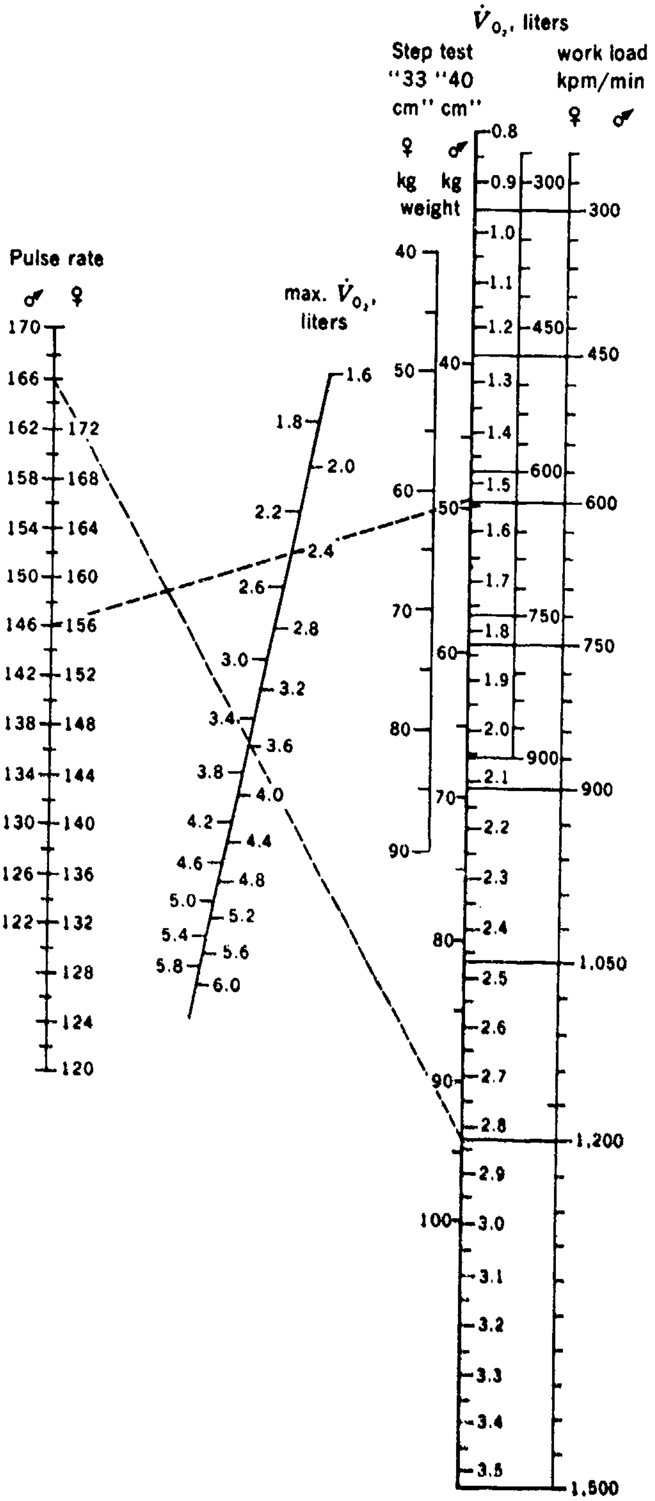
V̇O2, liters
Step test
"33 "40
cm" cm"
♀ ♂
kg kg
weight
work load
kpm/min
♀ ♂
Pulse rate
♂ ♀
max. V̇O2,
liters

FIGURE 9

TABLE 10 Max $\dot{V}O_2$ l/min - from Åstrand's Nomogram (MEN)

| LOAD kpm/min | 600 | 750 | 900 | 1050 | 1200 |
|---|---|---|---|---|---|
| HR | | | | | |
| 120 | 3.51 | 4.15 | 4.81 | 5.60 | - |
| 121 | 3.44 | 4.09 | 4.73 | 5.50 | - |
| 122 | 3.39 | 4.02 | 4.65 | 5.41 | - |
| 123 | 3.35 | 3.96 | 4.58 | 5.33 | - |
| 124 | 3.29 | 3.90 | 4.50 | 5.26 | - |
| 125 | 3.24 | 3.83 | 4.43 | 5.18 | 5.93 |
| 126 | 3.19 | 3.78 | 4.36 | 5.10 | 5.84 |
| 127 | 3.15 | 3.71 | 4.28 | 5.00 | 5.76 |
| 128 | 3.10 | 3.66 | 4.21 | 4.93 | 5.64 |
| 129 | 3.04 | 3.59 | 4.15 | 4.86 | 5.56 |
| 130 | 2.99 | 3.55 | 4.10 | 4.79 | 5.46 |
| 131 | 2.95 | 3.49 | 4.05 | 4.71 | 5.40 |
| 132 | 2.91 | 3.44 | 3.99 | 4.65 | 5.34 |
| 133 | 2.86 | 3.40 | 3.95 | 4.58 | 5.27 |
| 134 | 2.81 | 3.35 | 3.87 | 4.51 | 5.20 |
| 135 | 2.78 | 3.30 | 3.82 | 4.44 | 5.11 |
| 136 | 2.74 | 3.25 | 3.77 | 4.40 | 5.03 |
| 137 | 2.70 | 3.20 | 3.72 | 4.32 | 4.98 |
| 138 | 2.68 | 3.18 | 3.67 | 4.26 | 4.91 |
| 139 | 2.64 | 3.13 | 3.62 | 4.19 | 4.84 |
| 140 | 2.62 | 3.09 | 3.58 | 4.15 | 4.80 |
| 141 | 2.59 | 3.05 | 3.53 | 4.10 | 4.72 |
| 142 | 2.57 | 3.00 | 3.48 | 4.06 | 4.65 |
| 143 | 2.53 | 2.97 | 3.43 | 4.02 | 4.58 |
| 144 | 2.48 | 2.93 | 3.39 | 3.97 | 4.54 |
| 145 | 2.45 | 2.89 | 3.36 | 3.92 | 4.49 |
| 146 | 2.41 | 2.85 | 3.32 | 3.87 | 4.43 |
| 147 | 2.39 | 2.81 | 3.28 | 3.81 | 4.38 |
| 148 | 2.37 | 2.78 | 3.24 | 3.78 | 4.31 |
| 149 | 2.34 | 2.76 | 3.20 | 3.74 | 4.26 |
| 150 | 2.31 | 2.73 | 3.17 | 3.69 | 4.20 |
| 151 | 2.28 | 2.70 | 3.13 | 3.65 | 4.17 |
| 152 | 2.25 | 2.68 | 3.08 | 3.61 | 4.13 |
| 153 | 2.23 | 2.65 | 3.05 | 3.57 | 4.09 |
| 154 | 2.21 | 2.62 | 3.02 | 3.53 | 4.05 |
| 155 | 2.18 | 2.60 | 2.99 | 3.48 | 4.01 |
| 156 | 2.16 | 2.58 | 2.96 | 3.45 | 3.98 |
| 157 | 2.14 | 2.55 | 2.92 | 3.41 | 3.92 |
| 158 | 2.12 | 2.51 | 2.89 | 3.38 | 3.87 |
| 159 | 2.09 | 2.49 | 2.86 | 3.35 | 3.83 |
| 160 | 2.07 | 2.46 | 2.83 | 3.31 | 3.79 |
| 161 | 2.05 | 2.43 | 2.80 | 3.28 | 3.76 |
| 162 | 2.03 | 2.41 | 2.76 | 3.25 | 3.72 |
| 163 | 2.01 | 2.38 | 2.74 | 3.21 | 3.69 |
| 164 | 1.99 | 2.36 | 2.72 | 3.18 | 3.65 |
| 165 | 1.97 | 2.33 | 2.69 | 3.14 | 3.61 |
| 166 | 1.95 | 2.30 | 2.67 | 3.11 | 3.59 |
| 167 | 1.93 | 2.28 | 2.65 | 3.08 | 3.55 |
| 168 | 1.91 | 2.26 | 2.63 | 3.05 | 3.51 |
| 169 | 1.89 | 2.24 | 2.61 | 3.01 | 3.46 |
| 170 | 1.87 | 2.21 | 2.59 | 2.98 | 3.42 |

4. Wherever manual use of the nomogram was practised, it was read by 2 observers, mean results being taken. The nomogram used was a 3 x photographic enlargement of the nomogram given in Åstrand and Rodahl (1970), (approximately 60 x 30 cm).

APRE Survey method

5. For the computer program used in handling the 3171 sets of data obtained on the APRE survey of physical fitness in the Army a matrix of nomogram results were stored. This was obtained by taking the mean of 5 sets of max $\dot{V}O_2$ readings obtained by 5 observers who read the nomogram for all integer heartrates between 120 and 170 beats/min and workloads of 600, 750, 900, 1050 and 1200 kpm/min (Table 10).

6. This table is not conveniently modified to account for calibration errors of the cycle ergometers, so the observed heartrates were corrected before entry to the tabulated nomogram. The heartrate correction factors were obtained by manually reading the nomogram at high and low heartrates for both indicated and true cycle loads. Mean results were used to derive a heartrate correction-factor table which related cycle and indicated load. Table 11 gives an example.

TABLE 11 Corrections to observed heartrate, to allow for cycle calibration (Survey subjects 3443-3906)

| Cycle No | Indicated workload (kpm/min) | | | | |
|---|---|---|---|---|---|
| | 600 | 750 | 900 | 1050 | 1200 |
| 1 | 1.0980 | 1.0968 | 1.1045 | 1.1180 | 1.1285 |
| 4 | 0.9651 | 0.9657 | 0.9652 | 0.9646 | 0.9677 |
| 5 | 0.9477 | 0.9467 | 0.9456 | 0.9480 | 0.9490 |
| 6 | 0.9525 | 0.9467 | 0.9422 | 0.9415 | 0.9429 |

7. After correction of observed heartrate to allow for cycle calibration, and entry of the corrected heartrate into the nomogram matrix, the age correction factor was applied as before.

Shephard's method

8. Shephard (1970) presented equations which represented the nomogram to a sufficient accuracy, as judged by comparison with manual reading of the nomogram. In this method the net oxygen uptake of cycling is first calculated from workload assuming mechanical efficiency of 20% and this is added to a basal oxygen uptake calculated from surface area to obtain a gross oxygen uptake. This is applied to an equation representing a linear relation between heartrate and oxygen uptake, and the result is further modified by an age correction factor expressed in ratio form.

9. Since surface area was needed in this method, it was calculated by an approximation to the well known du Bois formula

$$\text{Area } (m^2) = 71.84 \; W^{0.425} \; H^{0.725} \times 10^{-4}$$

An approximation was required since the calculator in use at that time could not compute reciprocal powers but only square roots. The approximation was

$$\text{Area} = 45.91 W^{0.5} \; H^{0.75} \times 10^{-4}$$

where W, body weight is in kg and H, height is in cm in both cases.

10. The final calculation was

$$\frac{100}{100 + [1.37 \text{ (age)} - 33.2]} \times \frac{195-61}{P-61} \times 1/5 \; [(\text{load} \times 10.18) + (670 \times \text{area})]$$

where P is pulse rate. This consisted of 3 terms, the age correction, nomogram and oxygen uptake terms respectively.

11. In the present investigation of this method, the original du Bois formula was used for surface area, since a more powerful computer was available, and it was the representation of the nomogram rather than the approximation to du Bois which was under scrutiny.

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