MAXIMAL OXYGEN INTAKE ESTIMATED FROM SUBMAXIMAL HEART RATE

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ABSTRACT

This study investigated the predictability of maximal oxygen intake from three different submaximal heart rates assessed during an initial and follow-up ride on a cycle ergometer. Twenty-four healthy male subjects performed workloads of 600, 750, and 900 kpm's for six minutes on each of two visits to the laboratory. Analysis of variance for a randomised complete blocks design, with subjects constituting blocks, was used to analyse heart rate, estimated maximal oxygen intake, and residual estimated maximal oxygen intake variations among the experimental conditions. Relationships between the actual and estimated maximal oxygen intakes were determined using the Pearson Product-Moment formula of correlation. The average estimated maximal oxygen intake was significantly increased from the first testing occasion to the second. Although errors of estimation decreased significantly (450 ml to 366 ml) in favour of the second testing condition, the decrease was neither consistent with workloads nor subjects. The correlation coefficients were consistently low at 600 kpm for both testing occasions (0.68 and 0.73, respectively), consistently high at 750 kpm (0.82 and 0.84, respectively), and quite variable at 900 kpm (0.71 and 0.84, respectively), indicated that the validity of the nomogram was not consistent with all workloads or testing occasions. Despite these inconsistencies, the nomogram is, for practical purposes, a valid predictor of maximal oxygen consumption.

The maximum rate of work that can be performed is limited by the combined capacities of the respiratory and cardiovascular systems to take in, transport and use oxygen. Maximal oxygen intake measures the functional capacity of the cardiovascular system, and therefore is a useful criterion for the assessment of the overall capacity to perform work. The measurement of maximal oxygen intake is important to those persons in professions concerned with the implications of physical activity (or lack of it) and the human organism. Many investigators have endorsed maximal oxygen intake as the major component of physical fitness (Åstrand and Rodahl, 1970; Balke, 1959; Hermansen and Saltin, 1969). In the rehabilitation of heart disease patients one of the assessments clinicians must make is a determination of the level of work that patients can safely undertake in employment and leisure time activities.

Means of assessing maximal oxygen intake have been outlined by Taylor (1944); Åstrand (1952) and Balke (1960). These authors' procedures have serious limitations for practical use. All are fairly costly in terms of procedures, personnel, and laboratory equipment. The most serious objection, however, is the potential risk involved while performing the maximal test.

Several methods of estimating the maximal oxygen intake from physical characteristics at submaximal workloads have been proposed in an attempt to make the measurement more safe and practical (Åstrand and Ryhming, 1954; De Vries and Klafs, 1965; Glassford et al, 1965). The most widely accepted of these is the nomogram by Åstrand and Ryhming (1954) which estimates maximal oxygen intake from the measurement of heart rate at a single submaximal rate of work. The

nomogram was developed on the assumption that oxygen consumption and heart rate were linearly related over a wide range of values and thus, the slope of the oxygen consumption-heart rate curve could be extrapolated to an assumed maximum heart rate. Åstrand (1960) reported a correlation coefficient of 0.709 between the observed and estimated values of 129 males in the age range of 20-69 years, and a standard error of estimate of 430 ml. Several authors have independently obtained validity coefficients of approximately the same order as those reported by Åstrand (1960) (Baycroft, 1965; Glassford et al, 1965; Hermansen and Saltin, 1969).

Åstrand's and Ryhming's 1954 data showed that estimates of maximal oxygen intake apparently become better as the grade of work was increased (Åstrand and Rodahl, 1970). They further suggested that "psychological factors such as nervousness" could influence the pulse reaction for heart rates less than 120 beats per minute. The only guidelines given were that "best results" were obtained for heart rates between 120 and 170 beats/min.

It was the purpose of this study to investigate the predictability of maximal oxygen intake from three different submaximal heart rates assessed during subjects' initial and follow-up ride on a cycle ergometer.

METHODS

Twenty-four male college students with no previous exposure to laboratory work capacity assessment procedures served as subjects. No subject possessed any known pathological condition and all were physically

Fig. 1: Predicted $\dot{V}O_2 \text{ max}$ at 600, 750, and 900 kpm's vs. observed $\dot{V}O_2 \text{ max}$. Dashed line represents the line of identity.

active though not taking part in any regular physical training programme. Their ages, heights and weights are shown below in Table I.

TABLE I
Data of subjects in the study.

Mean age	20.6 years $\pm$ 1.56 years	range 18-24 years
Mean height	177.8 cm $\pm$ 7.7 cm	range 162-190 cm
Mean weight	81.6 kg $\pm$ 8.5 kg	range 60-98 kg

The testing was conducted in the University of Maryland Sports Medicine and Physical Fitness Center. All testing was conducted during the morning hours while the subjects were well rested and in a post-absorptive stage. The laboratory temperature was maintained at $22 \pm 2^\circ\text{C}$ but no control could be made over relative humidity. Work was performed on a Monark cycle ergometer.

Each subject performed at workloads of 600, 750, and 900 kpm's for six minutes on each of two visits to the laboratory. Following each workload performance, subjects sat quietly on the ergometer until predetermined resting heart rates were achieved before proceeding to the next higher workload.

Heart rates were recovered from the V_s electrocardiograph monitor. The average of the values assessed during the last two minutes at each workload were recorded as the steady state heart rates. These values were used with the Åstrand-Ryhming nomogram to predict maximal oxygen intake. Following all testing the actual maximum oxygen intake was measured in litres/min according to a modification by Falls (1964) of the method of work capacity assessment reported by Balke (1960) and by Taylor (1944). Direct measurements of oxygen intake were utilised. The subject's expired air was collected during the last 30 seconds of each minute in Douglas Bags. Volume expired was assessed by a gas meter with temperature and barometric pressure assessed at the time of volume determination.

Analysis of variance for randomised complete blocks design, with subjects' constituting blocks, was used to analyse heart rate, predicted maximal oxygen intake, and residual estimated maximal oxygen intake variations among the experimental conditions.

RESULTS AND DISCUSSION

The correlations between observed and estimated maximal oxygen intake, standard errors of estimate, and means are presented in Table II. Analysis of variance results for heart rate, estimated maximal oxygen intake, and residual estimated maximal oxygen intake are presented in Table III. The correlations were consistently low at 600 kpm's, consistently high at

TABLE II

Summary data for work conditions and days.

Statistic	Day	Work load — kpm		
		600	750	900
Correlation (Actual vs. Estimated)	1	0.688	0.832	0.711
	2	0.732	0.839	0.843
Standard error (VO ₂ max)	1	0.425	0.333	0.412
	2	0.399	0.319	0.315
Mean Heart Rate (Submaximal) b/m	1	125 ± 11	144 ± 12	160 ± 13
	2	121 ± 12	140 ± 14	157 ± 13
Mean Estimated VO ₂ max l/m	1	3.26 ± 0.52	3.03 ± 0.52	2.87 ± 0.41
	2	3.45 ± 0.61	3.18 ± 0.58	2.98 ± 0.41
Mean Residual Estimated VO ₂ max l/m	1	.365 ± 0.25	.429 ± 0.30	.586 ± 0.24
	2	.344 ± 0.21	.275 ± 0.26	.480 ± 0.23

750 kpm's and quite variable at 900 kpm's indicating that the validity of the nomogram is not consistent with all experimental conditions. In each case the coefficients were highest for the second visit to the laboratory, suggesting that more stable conditions apparently existed following that trial. Evidence of this was seen from the significant reduction in exercise heart rates, independent of workload, from the first to second test. Large intrasubject variability existed with respect to heart rate and consequently estimated maximal oxygen intake. Possible explanations for this include: (1) variable anxiety levels among subjects resulting in variable manifestations of anxiety (elevated exercise heart rate), and (2) an increase in work efficiency due to familiarity with the testing procedures. A significant F ratio for subjects was noted indicating intersubject variability

existed in terms of heart rate and consequently physical conditioning.

A comparison of estimated maximal oxygen intakes for the different workloads revealed that a significant decrease in mean values existed. In view of the fact that the mean observed maximal oxygen intake was 3.44 litres/min these results suggest that the nomogram tends to underestimate observed values. All except one estimated mean value was less than the observed mean. The tendency for the nomogram to underestimate maximal oxygen intake has been discussed previously (Rowell et al, 1964; Teraslinna and Ismail, 1966; Wyndham et al, 1974). The lack of a rectilinear relationship between near maximal values of heart rate and oxygen intake appears to be a reasonable explanation for general under-estimation. The fact that it varies with workloads, however, has not been systematically discussed. While an additive fatigue effect may have been carried over to the next higher workload, clarification of the relationship apparently awaits a better understanding of the interrelationships of the numerous artifacts associated with submaximal heart rate data.

A consideration of the correlation coefficients and residual estimated maximal oxygen intake mean values suggested that any workload may be utilised to estimate maximal oxygen intake with reasonable accuracy. Thus, workloads inducing heart rates as low as 120 beats/min may be utilised where risk of physical exertion is involved. Best estimates were obtained for submaximal heart rates between 140 and 145 beats/min. Workloads inducing higher rates may be utilised provided subjects are familiar with the testing facilities. In each case, some correction for the tendency to underestimate maximal oxygen intake should be considered. Methods for correction have been reported by Davies (1968) and Wyndham et al (1959).

TABLE III

Analysis of variance.

Source of Variation	Degrees of Freedom	Submaximal Heart Rate		Estimated Maximal Oxygen Intake		Residual Estimated Maximal Oxygen Intake	
		Mean Square	F-Ratio	Mean Square	F-Ratio	Mean Square	F-Ratio
Subjects (S)	23	850.1	64.4 ^b	1.37	49.7 ^b	.27	17.4 ^b
Workloads (W)	2	14939.5	477.6 ^b	2.25	34.6 ^b	.52	9.8 ^b
S X W	46	31.3	2.4 ^b	.07	2.4 ^b	.05	3.3 ^b
Days (D)	1	462.0	11.5 ^b	.84	8.4 ^b	.32	6.9 ^b
S X D	23	40.2	3.0 ^b	.10	3.6 ^b	.05	2.9 ^b
W X D	2	1.0	.1	.02	.7	.05	3.4 ^a
S X W X D	46	13.2		.03		.02	
Error	0						

^aSignificant at the .05 level

^bSignificant at the .01 level

CONCLUSIONS

The nomogram is for practical purposes a valid predictor of maximal oxygen intake despite the inconsistencies mentioned. Best estimates of maximal oxygen intake are made from submaximal heart rates of 140-145 beats/min. Workloads inducing heart rates about 145 beats/

min provide good estimates of maximal oxygen intake provided the subjects are completely familiar with the testing procedure and facilities. Maximal oxygen intake values derived from the nomogram however, generally underestimate actual maximal oxygen intake values.

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