COMPARISON OF EXTRAPOLATED MAXIMAL WORKLOADS FROM VARIOUS SUBMAXIMAL LOADS

by

ELLEN LORRAINE SMITH

B. S., Frostburg State College, 1977

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Health, Physical Education and Recreation

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1979

Approved by:

William B. Zuti
Major Professor

TABLE OF CONTENTS

LIST OF TABLES

Chapter 1

THE PROBLEM

Physical working capacity is measured most accurately by determination of maximal oxygen uptake (max $\dot{V}O_2$), which is the amount of oxygen consumed and utilized during maximal work (5). The test procedures used to determine max $\dot{V}O_2$ are time-consuming, expensive, and, most importantly, potentially dangerous to the subject.

Since the physiological stresses placed upon the body during maximal testing are extremely fatiguing and uncomfortable, alternate methods for estimating max $\dot{V}O_2$ have been investigated. Because of previous work the determination of physical working capacity through submaximal testing has become an accepted practice (5, 32, 13). The ACSM Guidelines do not recommend max testing without an attending physician; submaximal testing is preferred.

Various tests have been constructed which use different instrumentation for estimating the maximal values. The most economical and easily administered test is a step test. The only equipment needed is a bench and some way to maintain a constant stepping rate, usually a metronome. Several bicycle ergometer tests, which make use of a mechanical braking device to regulate the workload, have been developed for use in submaximal testing, and are superior to step tests, in that the external workload can be determined. Another commonly-used type of submaximal test is a treadmill test, which involves walking or running;

most often speed is held constant, while grade is increased. The main disadvantage in treadmill testing, as in step testing, is that the external work can not be determined exactly.

Selected submaximal tests, specifically the bicycle tests, are based on the assumption that a linear relationship exists between heart rate and workload (4, 13). When this is assumed, the extrapolation from any set of two submaximal workloads should yield the same predicted maximal endpoint. Regression equations and nomograms have been compiled from heart rates and corresponding workloads to simplify the prediction of maximal physical working capacity (PWC_{max}) (4, 34).

The existence of the linear relationship at higher levels of submaximal work is not consistently supported by all previous studies (12, 38, 39). Heart rates were observed to correspond linearly with workloads, until the stress level approached the maximal level (11). At an undetermined point below the maximal physical working capacity, the linear relationship deteriorated to an asymptotic curve which finally leveled at the maximal workload. Estimation with regression lines was found to consistently underestimate the actual maximal physical working capacity (11, 19).

Linear estimation of a maximal workload from submaximal data can not be accurate if the heart rate-workload relationship is not linear. However, if the error of estimation is insignificant, the currently used submaximal tests would be adequate as a screening measure for assessing maximal physical working capacity. Recognition of the importance of accurate assessment of predicted maximal working capacity indicated a need for this study. More exactly, this study was undertaken to test the linear relationship and the similarity of extrapolated endpoints obtained from submaximal testing. If the linear relationship is a faulty assumption, then the methods used to estimate maximal capacity are also at fault. If the use of different submaximal plotpoints to obtain the predicted max point results in a similar endpoint, then the established tests are reliable; the validity of the test measures is not guaranteed since actual maximal testing is necessary to check the estimations.

PROBLEM STATEMENT

This study investigated the practice of estimating maximal physical working capacity from submaximal data. More specifically, this study sought to determine if extrapolation from any two sets of submaximal workloads would supply the same PWC_{max}.

NULL HYPOTHESIS

The estimated maximal workload endpoints will be the same, from any two submaximal plotpoints.

ALTERNATE HYPOTHESIS

If the estimated maximal workload endpoints are different, then the linear relationship for all four submaximal plotpoints is not supported. As a result, the selection of a particular set of submaximal workloads will have a significant effect on estimation of maximal workloads.

LIMITATIONS

Certain factors which may have limited this study should be noted:

1. The subjects were endurance athletes, who were tested during the competitive season. Since some residual effects of training could not be completely eliminated prior to testing, fatigue may have influenced the data.

2. The times for testing were different between subjects and may have affected intersubject data, but each individual's test times were held constant.

3. This study did not max test the subjects; therefore, the use of predicted maximal values in the regression lines were not validated, since the true maximal values may have differed.

4. Subjects were not randomly selected since they were volunteers who were pretested to assure sufficient capacity to steady-state at 1050 kpm's. The subjects were very well-conditioned and not an average group sample.

DELIMITATIONS

The scope of this study and the confines for generalizations from the study were restricted by the following:

1. This study was delimited to 16 male endurance athletes at Kansas State University, 18 to 30 years of age, none of whom were trained cyclists.

2. The subjects were trained to ride the ergometer with six practice sessions. Therefore, the results of the study may not be extended to subjects who are not trained prior to testing.

DEFINITION OF TERMS

In order to provide optimal understanding of the study it is important to understand the specific meaning of the terminology used herein.

CoolDown

This period immediately followed the final minute of testing, and continued until the subject's heart rate had recovered to 100 bpm or less. Subjects pedalled at a reduced workload of zero to 300 kpm's, as they preferred.

Ergometer

A bicycle with a mechanical braking device to produce specific workloads which can be calculated.

Extrapolation

This mathematical procedure utilizes a regression line extending through two known points to a third unknown point to determine the extrapolated PWC_{max}.

Estimated maximal heart rate

Each subject's maximal heart rate was estimated by subtracting his age from 220 (1).

Kilopond meter (kpm)

One "kp" is the force acting on the mass of one kilogram at normal acceleration of gravity, through the distance of 1 meter.

Maximal work load

The greatest amount of work that the subject can complete at the maximal heart rate; max work load may be estimated from a linear regression line through two submaximal heart rates and dropped down to the work load which corresponds to the maximal heart rate.

Physical working capacity

The amount of work of which an individual is capable or the aerobic capacity of an individual to perform, otherwise known as PWC, can be defined at different levels of heart rate; PWC_{150}, PWC_{170}, PWC_{max} are defined as levels of work which produce heart rates of 150, 170 and maximal, respectively.

Steady-state

A subject's heart rate was the same, as determined by not more than four beats difference, for two consecutive minutes at each workload. Subjects pedalled a minimum of five minutes at each workload.

Thirty-beat count

Heart rates were measured by timing thirty consecutive heart sounds with a stop watch. The stop watch was started on the first sound, counted as zero, the next as one and so on. The time was recorded to the nearest tenth of a second, and the resultant time was converted to beats per minute (bpm). (See table in Appendix).

Warm-up

Prior to pedalling at a given test workload, each subject pedalled at a load of zero for one minute, to establish the correct pedalling rate, then pedalled at 300 kpm's for two minutes or until steady-stated.

Chapter 2

REVIEW OF LITERATURE

This chapter presents a review of pertinent literature related to testing of physical working capacity, specifically submaximal work tests, and their validity and reliability. The main divisions of the chapter are: (1) general introduction, (2) types of submaximal tests, (3) reliability and validity of predicted PWC_{max} values, (4) individual limitations in PWC testing, (5) testing protocol, and (6) summary of the chapter.

INTRODUCTION

Maximal oxygen uptake (max $\dot{V}O_2$) is considered one of the best measures for determination of fitness levels. The efficiency of the oxygen transport system is measured to determine the physical working capacity, which is defined as the maximum level of work of which an individual is capable (23).

Maximal testing supplies accurate and reliable information about heart rate, work loads and oxygen utilization which is useful, not only in evaluation of fitness, but in formulation of safe programs for developing fitness based on an individual's needs. The primary disadvantage of max testing arises from the potential danger involved in placing the subject under tremendous physiological stresses while maintaining a very highly elevated heart rate (5, 25, 38). Since the expense and availability make max testing impractical, alternate, less stressful methods of testing have necessarily been developed.

SUBMAXIMAL TESTS

Various submaximal tests have been constructed which utilize submaximal data (heart rate, work loads) to predict or estimate maximal data; that is, to predict maximal working capacity and max $\dot{V}O_2$. The basis for these predictions is an assumed linear relationship between heart rate and workload. From the estimated heart rate and work load, the max $\dot{V}O_2$ can also be estimated.

Submaximal tests may be subdivided into four general categories: field tests, step tests, treadmill tests and bicycle ergometer tests. Field tests can be used without laboratory equipment, such as the Cooper Twelve Minute Walk-Run Test (10). This test requires the subject to walk-run as far as possible in 12 minutes. The distance, with age as a limiting factor, is used to categorize the level of fitness.

Step tests make use of the recovery heart rate to obtain a value for max VO_2 per unit of body weight (13) and are based on the assumption that recovery is faster in better conditioned subjects. A step test is frequently chosen because a step is readily available, is inexpensive, requires no calibration and involves a more familiar form of exercise than cycling. Further, the energy expenditure is proportional to the body lift and independent (within limits) of the height of the step, stepping frequency, and body size (25). The Harvard (13) and Margaria (25) step tests differ in that the Margaria uses two workloads, since a common rest value of the heart rate can not be assumed.

Treadmill testing is also used for estimating max data, but involves the skill of locomoting on the treadmill (5). Another disadvantage in both step and treadmill testing is that the external work can not be determined absolutely (5).

Several submaximal bicycle ergometer tests are available which have a fixed and known workload and use one or two submaximal workloads to predict PWC_{max}. Ergometer tests are based on the assumption that a linear relationship between heart rate and workload exists. Probably the most well-known ergometer test is the Astrand-Ryhming test which estimates maximal $\dot{V}O_2$ from heart rate for one six-minute submaximal workload (4). This test requires only ten minutes per subject and is relatively inexpensive. An adjusted nomogram for calculation of PWC_{max} and max $\dot{V}O_2$ for males and females, by body weight, has been formulated to facilitate estimation (1, 4). In a study by Teraslinna et al. (33), standard deviations of max VO_2 and the corrected prediction of max VO_2 with the Astrand-Ryhming nomogram were determined. The correlation between the two values indicated that the nomogram, when corrected for age, was a satisfactory method of estimation.

Age of the subject is an inherent limitation within this test, since lower maximal heart rates for older subjects limit the capacity for oxygen intake (8). A mathematical analytic equation, using age and submaximal heart rate at a specific load has been developed to compensate for the age factor (27, 36).

The physical working capacity-170 test (PWC_{170}) is also based on the linear relationship of heart rate - workload, and consists of two consecutive six-minute ergometer workloads selected to produce heart rates of approximately 140 and 170 per minute (13, 32). A regression line is constructed extending to 170 beats per minute to predict the corresponding workload.

The choice of test is dependent on the size of the group being tested, available time, equipment and the proficiency of the tester. Bicycle ergometer tests require one piece of relatively inexpensive equipment, provide more controlled data than step or field tests, and are particularly advantageous since the external work can be determined. The current techniques of evaluating physical working capacity from submaximal data may need to be reassessed since some doubt exists on the validity of such predictions.

RELIABILITY AND VALIDITY IN PREDICTION OF PWC_{max}

The accurate prediction of maximal $\dot{V}O_2$ from exercise heart rate and VO_2 data collected at submaximal levels depends on 1) the linear relationship between the two variables, so that maximal heart rate and max VO_2 are reached at the same work intensity and 2) on the ability of subjects to reach a similar maximal heart rate (11). Several recent studies have suggested that these premises are not necessarily valid (12, 20, 26, 30, 38, 39).

In the Astrand-Ryhming prediction test, subjects were well-trained young adults, and results had a standard deviation of ten percent or less (8). As Rowell et al. (30) reported, max $\dot{V}O_2$ was underestimated by twenty-seven percent, plus or minus seven percent in sedentary subjects, and 5.6 percent, plus or minus four percent in endurance athletes.

This error possibly resulted because extrapolation was from some other maximal heart rate values than 195 per minute and max pulse rate decrease with increased training (12).

A linear relationship between heart rate and workload seems to have been observed to deteriorate as the subject nears maximal effort (11, 26, 38, 40). At low rates of work a straight line fits both $\dot{V}O_2$ and heart rate plots against workload. At higher workloads, the curve tends toward an asymptote (11, 30), which produces an underestimation of max $\dot{V}O_2$.

In addition the higher max heart rates in untrained individuals (30) produce an even greater underestimation of PWC_{max} when combined with the non-linearity of heart-rate-$\dot{V}O_2$ and workload regression line. In a study by Girandola et al. comparing $\dot{V}O_2$ prediction measures with ventilation, oxygen intake and work capacity from heart rate, correlations between heart rate and $\dot{V}O_2$ were low ($r = .06$ to $-.29$). Additionally, $\dot{V}O_2$ against heart rate at any minute of work was a poor predictor of work capacity ($r = .10$) (20).

Some support of the linear heart rate - workload relationship used in the Sjostrand and Astrand-Ryhming prediction tests has been shown in various studies (4, 5, 13, 21, 32). Astrand has defended the use of the Astrand-Ryhming nomogram for predictions, but stipulates that when accurate measures are necessary for research, actual max testing is preferable (38). The suggestion is made that more than one submaximal test should be carried out for accurate predictions.

In three separate experiments to test the validity of the Astrand-Ryhming nomogram, results seemed to support the use of the nomogram in estimations as adequate. It was specified, however, that the results were dependent on the use of 195 bpm as the prediction level for the population (21, 27, 34).

According to Wyndham, estimations from submaximal tests can be obtained if the following precautions are taken: 1) use of four different submaximal workloads; 2) heart rates at different loads range from 100 to 160 per minute; 3) oxygen consumption is measured, not estimated from workload - $\dot{V}O_2$ charts; 4) heart rate and $\dot{V}O_2$ are not measured before the tenth minute of exercise at each level of effort; and 5) a mean max heart rate is obtained for the population, considering age and altitude.

INDIVIDUAL LIMITATIONS IN PWC TESTING

Certain physical and psychological factors which have been recognized as influential in submaximal testing need to be controlled during testing to obtain reliable and valid results. Several of these factors have been statistically controlled with nomograms and correction regression equations (4, 23).

As previously stated, age is a serious limiting factor in submaximal testing (1). Since the lower arterio-venous oxygen differences and the relatively low hemoglobin concentrations (22), combined with the lower maximal heart rate in older people (2, 3, 39), produce incorrect estimates, correction factors are needed in PWC estimation.

The physical condition, as well as the training of the subject, may cause a tremendous underestimation of max $\dot{V}O_2$, while training produces a decrease in the percent error in estimation (11, 30). Contrary to this supposition, Froelicher et al. stated that physical conditioning was not a factor, since test time can increase without increase in aerobic capacity (19). Rather, performance time seemed to be influenced more by experience and anxiety.

Using four test procedures, obese women were compared to lean women, and conclusions were that physical condition is an important variable in fitness testing (28). This study also concluded that the obese may have lower average motor ability and agility, thus necessitating different measuring techniques. It should be noted that Astrand suggested that the Astrand-Ryhming nomogram is only useful when testing fairly well-trained individuals; other means may be necessary when testing other groups (8). In general fitness testing of females, the smaller dimensions of the heart produce a smaller cardiac output, subsequently resulting in lower max $\dot{V}O_2$ values than for males (3).

Psychological factors may affect submaximal testing by producing increases or decreases in the heart rate. Motivation effects were measured on PWC values, and the conclusion was reached that reduced inhibitions and increased tolerance to higher levels of anaerobic metabolites produced variations in PWC values (37). The pulse rate can vary independently of the $\dot{V}O_2$, but directly with the emotional state or level of excitement of the subject (31). Other extraneous factors found to influence heart rate were: elapsed time after last meal, total circulating hemoglobin, degree of hydration and alterations in ambient temperatures (31).

TESTING PROTOCOL

Numerous bicycle ergometer tests have established certain procedures which are generally accepted as standard. The most commonly used pedalling rates, temperatures for testing, criteria for defining steady-state, duration of exertion, and the importance of mechanical efficiency have appeared in the literature. These are outlined in this section.

The pedalling rate in ergometer testing is varied depending on the stress level of work. At workloads which approach the maximal level, a rate of 60 rpm seems to produce the highest maximal oxygen uptake (5, 13, 18). However, at submaximal workloads, 50 rpm is the most suitable rate for the greatest mechanical efficiency (5, 21, 28).

Conditions for fitness testing are necessarily standardized to insure repeatable test measures. The suggested standard temperature is 64 to 68 degrees F (5, 11, 13). However, as emphasized by deVries, this temperature range is only applicable to lightly-clothed subjects (13).

Submaximal testing which uses heart rate as the monitoring criteria requires that the heart rate reach a steady-state level. Steady-state has been defined as two consecutive heart rates which do not differ more than five beats, not measured before the fifth minute of exertion (5, 21). As a result of the time stipulation, the duration of work (minimum period) is determined to be at least five minutes and usually no more than six minutes (5, 11, 21, 28, 34).

The importance of practice to develop mechanical efficiency was emphasized by several authors (11, 14, 18). In any skill-related activity, learning through the development of mechanical efficiency occurs.

This must be controlled as a factor in heart rate studies by providing practice - training sessions prior to actual testing.

SUMMARY

Research has indicated that submaximal testing is a viable alternative to maximal testing, which has inherent disadvantages. Submaximal testing, using step tests, treadmill and bicycle tests, supplies sufficient data to estimate the maximal physical working capacity and maximal oxygen uptake.

Prediction of PWC_{max}, using heart rate as a measure of physical stress, is based on an assumed linear relationship between the heart rate and workload. Although the existence of such a relationship has been widely accepted, recent studies have cast doubt that the relationship is not linear at high workloads. The graph seems to deteriorate to an asymptote which produces an underestimation of PWC_{max}. A variety of physical and psychological factors have been noted which should be controlled in studies using heart rates. The age, physical condition, gender, and motivation or excitation levels may produce changes in heart rate, independent of the working capacity.

Specific procedures have been suggested which should be adhered to in order to standardize testing. These include pedal rate, temperature, and practice prior to testing.

Chapter 3

PROCEDURES

This chapter outlines the procedures used in conducting the study. The chapter elaborates on the following topic areas: the subjects, methods, the test, and the statistical method used. The study was conducted at Kansas State University using the facilities of the Health, Physical Education and Recreation Department. A proposal of the study was submitted to and approved by the department's human rights committee. Before testing, all subjects signed an informed consent form which briefly outlined the purpose, procedures and risks involved in the study (see appendix).

THE SUBJECTS

Sixteen male endurance athletes at Kansas State University, eighteen to thirty years of age, volunteered to participate in the study. All subjects were capable of steady-stating submaximally at less than eighty-five percent of their estimated max heart rate at a workload of 1050 kpm. Fifteen subjects were long distance runners and one was an endurance swimmer.

The mean age of the subjects was 22.06 years with a mean weight of 73.49 kilograms.

METHOD

Prior to testing, each subject underwent six practice sessions which followed the same procedures as the actual test sessions. This was to eliminate learning of mechanical efficiency as a factor in the test.

Subjects were tested at the same time of day for each of two trials and were instructed to restrict their food intake and physical activity three hours prior to testing. Preparations and tests were performed with only the subject and the investigator present in the laboratory.

Air temperature was held constant throughout the testing at approximately 68 degrees F. Heart rates were counted by the 30 beat count method using a stethoscope and stopwatch.

Subjects, wearing only athletic shorts and socks, were weighed on a balance beam scale to the closest one-fourth ounce. This was converted to kilograms to maintain consistency since the ergometers were calibrated in metric units. This was done to compute each subject's estimated oxygen uptake per unit of body weight. Subjects were instructed to sit quietly for five minutes after which a resting heart rate was taken.

The bicycle ergometer seat was adjusted to the height at which the subject could fully extend the knee while pedalling with the ball of the foot. The height was recorded and kept constant for each test. Due to some irritation from the seat rubbing the inner thighs, some subjects chose to use a piece of foam rubber padding on the seat.

A metronome, set at a pace of 50 rpm or 100 beats per minute, was placed in front of the subject. A 60-second sweep clock, situated for easy access by the investigator, was started as soon as the subject began pedalling.

THE TEST

An initial one-minute period of free-wheeling was followed by a warm-up of 300 kpm's which lasted for two to three minutes. The test was not continued if the warm-up heart rate was more than 90 bpm. The subject pedalled at the consecutive workloads of 600 and 900 kpm's or 750 and 1050 kpm's.

After the warm-up period, the workload was increased arbitrarily to either 600 or 750 kpm's with heart rates measured during the last fifteen seconds of minutes one, two, three, four, five, and six if necessary. After the third minute of work, heart rates were taken at the end of minutes four and five; and, if within four beats, the subject was considered steady-stated, work was then increased to either 900 or 1050 kpm's respectively. A sixth minute of work was necessary if steady state had not been reached. The same protocol was followed for the higher workload.

Upon cessation of the final minute of work, subjects were allowed a cool-down period sufficient to recover the heart rate to below 100 bpm. Cool-down was usually at a level of zero to 300 kpm's. The final heart rate for each workload was computed as the actual final heart rate, not as the average of the last two measurements.

The final heart rates for each of the four workloads were graphed against the corresponding workloads and regression lines were constructed to the estimated max heart rate. From this point, an extrapolated maximal workload could be estimated.

THE STATISTICAL TREATMENT

The data were analyzed using a paired t-test for related samples to compare the difference, if any, between the estimated maximal endpoints determined from the regression lines.

Chapter 4

RESULTS AND DISCUSSION

This study compared estimated values of PWC_{max} from two sets of submaximal workloads, using sixteen well-trained male subjects. This chapter presents the results obtained from the study and a discussion of those results.

RESULTS

Steady-state heart rates for the final minute of exertion at each of four workloads, 600, 750, 900, 1050 kpm's, were measured and are shown in Table 1. Regression lines for workloads 600 and 900 and 750 and 1050 were constructed to predict the subjects' estimated maximal workload. The regression line was solved by estimating the maximal heart rate to determine the estimated max workload (see appendix for graphs).

Table 2 shows the mean, standard deviation, variance, standard error of the mean, and standard error of the difference for each set of workloads. Using a paired t-test for related samples, the mean differences were not significant ($p = .05$ level).

Table 1

Raw Data

Subject	Age (yrs)	Wt. (kg)	Workload (kpm)	H.R. (bpm)	Est. PWC_{max} (kpm/min)	Subject	Age (yrs)	Wt. (kg)	Workload (kpm)	H.R. (bpm)	Est. PWC_{max} (kpm/min)
102	26	64.5	600	91	2560	114	18	70.3	600	99	1630
			900	108					900	129	
			750	107	2030				750	113	2160
			1050	130					1050	132	
105	30	72.7	600	90	1710	115	21	67.5	600	97	2400
			900	117					900	114	
			750	97	1400				750	105	2100
			1050	140					1050	126	
106	19	79.6	600	99	2230	119	20	66.4	600	108	1610
			900	118					900	135	
			750	116	1700				750	115	2090
			1050	143					1050	134	
108	23	73.9	600	93	1440	120	19	62.3	600	105	2105
			900	130					900	124	
			750	109	1350				750	124	1350
			1050	153					1050	153	
109	30	68.4	600	114	1620	121	21	64.1	600	102	1570
			900	136					900	132	
			750	113	1520				750	120	1830
			1050	143					1050	142	
110	22	76.8	600	109	1270	203	21	77.3	600	107	1800
			900	149					900	130	
			750	131	1360				750	118	1670
			1050	162					1050	144	
111	19	72.9	600	97	2075	207	22	77.6	600	96	2140
			900	118					900	116	
			750	99	2025				750	109	2085
			1050	123					1050	129	
112	21	86.5	600	102	2560	208	21	95.1	600	100	2170
			900	117					900	119	
			750	108	2060				750	113	1610
			1050	129					1050	143	

Table 2

General Statistics for t-test

Work	N	Mean	Standard Deviation	Variance	S. E. of Mean
900	16	1930.5625	401.46289	161,172.375	100.36572
1050	16	1783.4375	295.95288	87,588.125	73.98822

Test	S. E. of Difference	Mean Difference	D.F.	t	Prob.
paired	89.08331	147.1250	15	1.652	0.120

DISCUSSION

The results showed no significant difference between the mean estimated max workloads, but a difference between the raw values did exist. Therefore, there would seem to be a trend to overestimate the maximum when using lighter workloads. However, an error of plus or minus ten percent is within acceptable established standards (8).

With adequate practice sessions and standardized testing conditions, using well-trained subjects, the test as described here is sufficient for screening purposes. However, the results indicate that selection of workload based on heart rate (31) rather than choosing the same specific workloads for all subjects would supply more valid estimations of working capacity. The tests which employ heart rate as a measure must elicit a heart rate between 140 and 170 bpm (31). Essentially this suggests that workload criterion does not influence the final estimation point.

Since the data support the null hypothesis, the existence of the linear relationship may be considered valid, since the endpoints from different plotpoints were the same. However, these findings should not be overgeneralized from the data presented in this study for the following reasons.

The number of subjects and their high level of fitness greatly limits the extensibility of the results. Statistically, the test would be more powerful with a larger sample (34). The condition of the subjects prevented elicitation of heart rates (at the selected workloads) close enough to their 85 percent max to indicate non-linearity at the extreme upper limit of the heart rate - workload graph. Selection of higher workloads may have produced significantly different endpoints.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

Final heart rates for four submaximal workloads have been graphed to extrapolate an estimate of PWC_{max} for well-conditioned males. The following conclusions and recommendations are made based on the obtained results from this study.

CONCLUSION

The arbitrary selection of submaximal workloads does not produce a significant difference in the final estimate of PWC_{max} with well-trained individuals. Further, the results of this study indicate that the reliability in estimation allows for the continued use of submaximal prediction testing as screening measures. It is important to note that the validity of the measures was not investigated since actual max testing was not carried out.

RECOMMENDATIONS FOR FURTHER STUDY

It is recommended that further research is necessary with certain adaptations to the study. The study should be repeated under the following conditions:

1. Since some question exists about testing females, this study should be conducted on women subjects.

2. Since the results were different, although not significantly, the study should be repeated using additional subjects.

3. Subjects of different ages and levels of physical fitness should be tested since this study applied only to well-conditioned subjects.

SELECTED BIBLIOGRAPHY

1. Astrand, I. "Aerobic work capacity in men and women with special reference to age," Acta Physiologica Scandinavica, 49, Supplement 169, 1960.

2. Astrand, I. "Degree of strain during building work as related to individual aerobic work capacity," Ergonomics, 10:293-303, 1967.

3. Astrand, I., et al. "Maximal heart rate during work in older men," Journal of Applied Physiology, 14(4):562-566, 1959.

4. Astrand, P. O. and I. Ryhming. "A nomogram of calculation of aerobic capacity (physical fitness) from pulse rate during submaximal work," Journal of Applied Psychology, 7:218-21, September, 1954.

5. Astrand, P. O. and K. Rodahl. Textbook of Work Physiology. New York: McGraw-Hill, 1970.

6. Astrand, P. O., et al. "Maximal oxygen uptake and heart rate in various types of muscular activity," Journal of Applied Physiology, 16(6):977-981, 1961.

7. Astrand, P. O., et al. "Cardiac output during submaximal and maximal work," Journal of Applied Physiology, 19(2):268-274, 1964.

8. Astrand, P. O. "Commentary," Canadian Medical Association Journal, 96:742-743, 1967.

9. Auchincloss, J. and R. Gilbert. "Estimation of maximum oxygen uptake with a brief progressive stress test," Journal of Applied Physiology, 34:525, 1973.

10. Cooper, K. "A means of assessing maximal O_2 intake," Journal of the American Medical Association, 203:201-204, 1968.

11. Davies, C. "Limitations to the prediction of maximum oxygen intake from cardiac frequency measurements," Journal of Applied Physiology, 24:700-706, 1968.

12. Davies, C. "Commentary," Canadian Medical Association Journal, 96:744, 1967.

13. deVries, H. Physiology of Exercise. Dubuque, Iowa: William Brown Co., 1974.

14. Ekblom, B. "Effect of physical training on circulation during prolonged severe exercise," Acta Physiologica Scandinavica, 78:145-158, 1970.

15. Ekblom, B., et al. "Effect of training on circulatory response to exercise," Journal of Applied Physiology, 24(4):518-528, 1968.

16. Ekblom, B. and L. Hermansen. "Cardiac output in athletes," Journal of Applied Physiology, 25:619-625, 1968.

17. Fox, E. "A simple accurate technique for predicting maximal aerobic power," Journal of Applied Physiology, 35:914, 1973.

18. Froelicher, V., et al. "A comparison of three maximal treadmill exercise protocols," Journal of Applied Physiology, 36:720, 1974.

19. Girandola, R. and Katch, H. "Prediction of oxygen intake from ventilation, and oxygen intake and work capacity from heart rate during heavy exercise," Research Quarterly, 42:362-373, 1971.

20. Glassford, R., et al. "Comparison of maximal oxygen uptake values determined by predicted and actual methods," Journal of Applied Physiology, 20(3):509-513, 1965.

21. Grimby, G., et al. "Cardiac output during submaximal and maximal exercise in active middle-aged athletes," Journal of Applied Physiology, 21(4):1150-1156, 1966.

22. Hermiston, R. and J. Faulkner. "Prediction of maximal oxygen uptake by stepwise regression technique," Journal of Applied Physiology, 30(6):833-837, 1971.

23. Linderholm, H. "Diffusing capacity of the lungs as a limiting factor for physical working capacity," Acta Medica Scandinavica, 163:61-84, 1959.

24. Margaria, R., et al. "Indirect determination of maximal oxygen consumption in man," Journal of Applied Physiology, 20(5):1070-1073, 1965.

25. Maritz, J., et al. "A practical method of estimating an individual's maximal oxygen intake," Ergonomics, 4:97-122, 1961.

26. Metz, K. and J. Alexander. "Estimation of maximal oxygen intake from submaximal work parameters," Research Quarterly, 42:187-193, 1971.

27. Moody, D. and K. Buskirk. "Evaluation of aerobic capacity in lean and obese women with four test procedures," Journal of Sports and Medicine and Physical Fitness, 9:1-9, 1969.

28. Rodahl, K., et al. "Physical work capacity," Archives of Environmental Health, 2:499-510, 1961.

29. Rowell, L., et al. "Limitations to prediction of maximal oxygen intake," Journal of Applied Physiology, 19(5):919-927, 1964.

30. Saltin, B. and P. O. Astrand. "Maximal oxygen uptake in athletes," Journal of Applied Physiology, 23(3):353-358, 1967.

31. Sjostrand, T. "Changes in the respiratory organs of workmen at ore smelting works," Acta Medica Scandinavica, Supplement 196:687-699, 1947.

32. Taylor, H. and L. Rowell. "Exercise and metabolism," Science and Medicine of Exercise and Sport, 2:84-111, 1974.

33. Teraslinna, P., et al. "Nomogram by Astrand and Tyhming as a predictor of maximum oxygen uptake," Journal of Applied Physiology, 21(2):513-515, 1966.

34. Van Dalen, D. Understanding Educational Research. New York: McGraw-Hill, 1973.

35. Von Dobeln, W., et al. "An analysis of age and other factors related to maximal oxygen uptake," Journal of Applied Physiology, 22(5):934-938, 1967.

36. Wilmore, J. "Influence of motivation of physical work capacity and performance," Journal of Applied Physiology, 24:459-463, 1968.

37. Wyndham, C. "Submaximal tests for estimating maximum oxygen intake," Canadian Medical Association Journal, 96:736-742, 1967.

38. Wyndham, C. and J. Ward. "An assessment of the exercise capacity of cardiac patients," Circulation, 16:384-393, 1957.

39. Wyndham, C., et al. "Maximum oxygen intake and maximum heart rate during strenuous work," Journal of Applied Physiology, 14(6):927-936, 1959.

APPENDIX A

Data Forms

INFORMED CONSENT FORM

I ______________________________ have volunteered to participate in an experiment which is designed to validate procedures for extrapolating PWC_{170} values from different submaximal plotpoints. I have been asked to complete the study, which will conclude Dec. 2, 1978, but I should feel free to withdraw at any time. I understand that I may refuse to undergo any of the testing procedures without prejudice.

I will be required to attend 6 practice sessions and 2 testing sessions, each of which will last from 10 to 20 minutes. I will feel free to ask questions about any of the testing procedures. All results will be kept strictly confidential; each subject will be assigned a code number which will only appear with the name on the consent form and on the master list, available only to the investigator and project advisors. I will be given an opportunity to find out the conclusions of the study when all testing has been completed.

To the best of my knowledge, I am in a good state of health and have no cardiovascular or respiratory problem or disease which would limit my participation in this study.

Testing will follow these procedures:

1. All sessions will begin with a one-minute warmup period without resistance on the bicycle ergometer.
2. Each practice session will involve two submaximal workloads, and the subject will ride 3-6 minutes, until steady-stated.
3. Each test session will involve two submaximal workloads, 600 and 900, or 750 and 1050. Duration of rides will be the same as for the practice sessions.
4. All sessions will finish with a cooldown period sufficient to bring the heart rate down to 100 beats per minute.
5. The investigator will monitor heartrates continuously during all testing. Anyone having a heart rate higher than 85% of their estimated maximal heart rate will be stopped at that time.

I have read and fully understand the above statement. I hereby voluntarily consent to participate in the study.

______________________________ Signature

______________________________ Witness

____________________ Date

____________________ Code Number

PWC TESTING: SMITH

NAME ______________ AGE ______ HEIGHT OF SEAT ______________

ESTIMATED MAX HEART RATE: 220-age= ________ 85% MAX H.R. ______ % FAT ______ ABDOM ______ PECT ______ TRIC ______

DATE I	II	III	IV	V	VI
rest h.r. ______	rest h.r. ______	rest h.r. ______	rest h.r. ______	rest h.r. ______	rest h.r. ______
rest bp ______	rest bp ______	rest bp ______	rest bp ______	rest bp ______	rest bp ______
300 kgm warm-up	300 kgm warm-up	300 kgm warm-up	300 kgm warm-up	300 kgm warm-up	300 kgm warm-up
______ 1st min.	______ 1st min.	______ 1st min.	______ 1st min.	______ 1st min.	______ 1st min.
______ 2nd min.	______ 2nd min.	______ 2nd min.	______ 2nd min.	______ 2nd min.	______ 2nd min.
______ 3rd min.	______ 3rd min.	______ 3rd min.	______ 3rd min.	______ 3rd min.	______ 3rd min.
______ final	______ final	______ final	______ final	______ final	______ final
______ kgm work	______ kgm work	______ kgm work	______ kgm work	______ kgm work	______ kgm work
______ 2nd min.	______ 2nd min.	______ 2nd min.	______ 2nd min.	______ 2nd min.	______ 2nd min.
______ 3rd min.	______ 3rd min.	______ 3rd min.	______ 3rd min.	______ 3rd min.	______ 3rd min.
______ 4th min.	______ 4th min.	______ 4th min.	______ 4th min.	______ 4th min.	______ 4th min.
______ 5th min.	______ 5th min.	______ 5th min.	______ 5th min.	______ 5th min.	______ 5th min.
______ final	______ final	______ final	______ final	______ final	______ final
______ kgm work	______ kgm work	______ kgm work	______ kgm work	______ kgm work	______ kgm work
______ 2nd min.	______ 2nd min.	______ 2nd min.	______ 2nd min.	______ 2nd min.	______ 2nd min.
______ 3rd min.	______ 3rd min.	______ 3rd min.	______ 3rd min.	______ 3rd min.	______ 3rd min.
______ 4th min.	______ 4th min.	______ 4th min.	______ 4th min.	______ 4th min.	______ 4th min.
______ 5th min.	______ 5th min.	______ 5th min.	______ 5th min.	______ 5th min.	______ 5th min.
______ final	______ final	______ final	______ final	______ final	______ final

INVESTIGATOR ______________________

PRACTICE SESSIONS

CONVERSION FOR 30 PULSE BEATS

Sec.	HR/min.
22.0	82/min.
21.9	83
21.8	83
21.7	83
21.6	83
21.5	84
21.4	84
21.3	85
21.2	85
21.1	85
21.0	86
20.9	86
20.8	87
20.7	87
20.6	87
20.5	88
20.4	88
20.3	89
20.2	89
20.1	90
20.0	90
19.9	90
19.8	91
19.7	91
19.6	92
19.5	92
19.4	93
19.3	93
19.2	94
19.1	94
19.0	95
18.9	95
18.8	96
18.7	96
18.6	97
18.5	97
18.4	98
18.3	98
18.2	99
18.1	99
18.0	100
17.9	101
17.8	101
17.7	102
17.6	102
17.5	103
17.4	103
17.3 sec.	104/min.
17.2	105
17.1	105
17.0	106
16.9	107
16.8	107
16.7	108
16.6	108
16.5	109
16.4	110
16.3	110
16.2	111
16.1	112
16.0	113
15.9	113
15.8	114
15.7	115
15.6	115
15.5	116
15.4	117
15.3	118
15.2	118
15.1	119
15.0	120
14.9	121
14.8	122
14.7	122
14.6	123
14.5	124
14.4	125
14.3	126
14.2	127
14.1	128
14.0	129
13.9	129
13.8	130
13.7	131
13.6	132
13.5	133
13.4	134
13.3	135
13.2	136
13.1	137
13.0	138
12.9	140
12.8	141
12.7	142
12.6 sec.	143/min
12.5	144
12.4	145
12.3	146
12.2	148
12.1	149
12.0	150
11.9	151
11.8	153
11.7	154
11.6	155
11.5	157
11.4	158
11.3	159
11.2	161
11.1	162
11.0	164
10.9	165
10.8	167
10.7	168
10.6	170
10.5	171
10.4	173
10.3	175
10.2	176
10.1	178
10.0	180
9.9	182
9.8	184
9.7	186
9.6	188
9.5	189
9.4	191
9.3	194
9.2	196
9.1	198
9.0	200
8.9	202
8.8	205
8.7	207
8.6	209
8.5	212
8.4	214
8.3	217
8.2	220
8.1	222
8.0	225

COMPARISON OF EXTRAPOLATED MAXIMAL WORKLOADS FROM VARIOUS SUBMAXIMAL LOADS

by

ELLEN LORRAINE SMITH

B. S., Frostburg State College, 1977

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Health, Physical Education and Recreation

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1979

Sixteen well-trained male athletes of Kansas State University, aged 18 to 30 years, volunteered to participate in a submaximal bicycle ergometer study, using four submaximal workloads. Steady-state heart rates for workloads of 600 and 900, or 750 and 1050 kpm's, were measured after at least five minutes of work on two test days. Final-minute heart rates were graphed against the corresponding workloads. Regression lines were constructed, then extended to the subjects' estimated maximal heart rate. From that point, the corresponding workload was defined as the estimated PWC_{max}. A paired t-test for related samples was used to analyze the difference between the two estimated maximal endpoints obtained from the regression lines. Findings indicated no significant differences at the .05 level.