THE EFFECT OF TWO METHODS OF INTERVAL TRAINING ON THE PHYSICAL PERFORMANCE AND OXYGEN RECOVERY CURVES OF ROWERS

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ABSTRACT

The effectiveness of two training methods was examined. Two equally fast varsity 'four-oar' crews were assigend to two interval training programs in the late stages of preparation for the competitive season. The three experimental testings measured total work performance completed in six minutes on the rowing ergometer and total oxygen consumption in 15 minutes of recovery. Improvement in the slope and the rate of the fast phase and the slow phase of the oxygen debt curve provided additional criteria in judging the superiority of one method over the other.

All rowers were expected to improve their rowing performance as well as their total oxygen debt after an eight-week training program. The rowers following training program A were expected to show greater improvement in all testing parameters than the rowers following training program B.

A theoretical exponential function of the form $A = A_1e^{-K_1t} + A_2e^{-K_2t}$ was fitted to the oxygen data in recovery for all subjects in all three testings. Parameters of the oxygen debt curve, A_1, K_1, A_2, K_2, were calculated and treated statistically. Analysis of variance was used in order to study the effect of training and the effect of the two training methods on the experimental subjects.

The results showed a satisfactory fit of the theoretical function to the experimental data of oxygen consumption. The oxygen debt curves after an exhaustive rowing exercise were similar in shape to curves obtained in moderate exercise by other experimenters.

The results showed that there was a significant statistical improvement over trials in rowing performance, total oxygen debt, and A_1 parameter of oxygen debt curve for the rowers as a total group. The increase in A_1 was presumably due to the ability of the subjects to maintain a higher oxygen consumption in the terminal stage of work in the last testing. There was no significant difference between the two training programs in any of the test parameters. The results obtained, however, were in the direction expected by the stated hypotheses.

The rowers who followed training program A reported slightly higher values for subjective feelings of tiredness immediately after interval rowing session and on the following day. This was as expected.

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CHAPTER I

INTRODUCTION TO THE PROBLEM

Rowing is not a sport which lends itself easily to study. It is therefore not surprising to find a paucity of information concerning this activity in the literature. Only in recent years have serious attempts been made to remedy this situation. One aspect of rowing science which has received attention in the expanding literature is that which deals with aerobic and anaerobic metabolism during racing. The question of relative contributions of aerobic and anaerobic metabolism to the work of rowing has not been answered satisfactorily yet. Adam (1), Robertson (80), and Samsonov (85,86) regard aerobiosis and anaerobiosis as equal partners in the provision of energy. Hagerman (35), on the contrary, emphasizes the aerobic metabolism as the source of most of the energy provided for rowing in competition. The results of his research (32, 33, 34, 35) indicate a marked aerobic response of the rower during each of the six minutes rowing effort. The average oxygen debt seemed rather low as compared to the aerobic metabolism requirements, thus suggesting that aerobic metabolism is the source of most of the energy provided for rowing exercise. Hagerman's findings are substantiated by extensive research carried out with oarsmen in the German Democratic Republic (20).

Ideally, then, according to Hagerman, an oarsman's conditioning program should include high quality prolonged work of 70 percent to 80 percent maximal capacity and this work should take up at least 80 percent of his total training time. Interval training and anaerobic speed play are valuable additions to the program which has as part of its objectives specific conditioning for sprints during the race and a finishing kick at the end.

The major consideration in the preparation of a training program should thus be task specificity. Endurance and speed can be developed compatibly by concentrating on separate specific tasks that elicit maximal responses from either aerobic or anaerobic pathways. The greatest aerobic response comes from training stimuli involving long distance and fartlek work, while anaerobic metabolism is facilitated by interval or anaerobic fartlek training. Hagerman (33) suggests concentration of interval work only as major regattas near. This intense work seems to improve the athlete's ability to resist acute fatigue and improve anaerobic capacity, so important during the sprint and final kick of the race. Interval training has two distinct advantages over the longer work. It permits the crew to sample intermittent bouts of work at race pace which are necessary if the crew is to be properly prepared neuromuscularly and the physical discomfort experienced as a result of accumulative efforts conditions the crew for similar experiences which will most likely occur during the sprint.

No exact scientific means has yet proven fully successful in assessing the correct recovery period for athletes in interval training. The most recognized authorities in track and field, where most of the research has been undertaken and ultimately copied by rowing coaches, are of the opinion that the intensity of the demand in each bout of exercise should be faster than the target racing speed. Experience of leading rowing coaches has shown that faster than the target racing speed in interval training over 500 to 600 metres can be achieved only if recovery periods become progressively longer in a training session or if number of repetitions remains relatively small (up to six). In so doing, however, the main purpose of interval training, namely, to elicit the maximal response of the anaerobic pathway, is reduced significantly.

The present study was undertaken in order to investigate if there are still better training procedures which can elicit higher responses from anaerobic mechanisms than the conventional training methods previously tried.

The Purpose

The purpose of this study is to determine whether or not one training procedure used in the preparation of varsity rowers for competitive rowing is superior to another. Both are similar in respect to the total distance rowed, but are qualitatively different in the adaptive

response required of the anaerobic mechanisms during hard interval work.

The Problem

The problem of the study is to examine if one interval training method (A) is superior to another interval training method (B) using several criteria of performance. Both methods require equal amounts of work and allow equal amounts of rest time per training session. However, the patterns of power output during interval training sessions are likely to be in distinct contrast to each other.

Method (A) is an interval training program where times between workbouts decrease throughout the interval training session. It is designed to condition the crew for similar exhausting experiences which will most likely occur during the sprint and final kick of the race by the physical discomfort experienced as a result of accumulative efforts and progressively increased amounts of oxygen debt carried over from workbout to workbout.

Method (B) is an interval training program in which the times between workbouts increase, i.e. there are progressively longer recovery periods throughout the daily training period. It is designed to equilibrate the amount of oxygen debt carried over from one workbout to another.

Criteria to be Used in Judging the Superiority of Method (A)

1. Improvement in total work performance completed in six minutes on the rowing ergometer from week one to week four and week eight.

2. Improvement in oxygen debt from week one to week four and week eight as determined by the following characteristics:

a. improvement in total oxygen debt collected for 15 minutes after exercise during week one, week four and week eight;

b. improvement in the slope of the fast phase and slow phase of the oxygen debt curve;

c. improvement in the rate of oxygen consumption of the fast phase and slow phase of the oxygen debt curve.

3. Two subjective written responses of the rowers about the state of their tiredness after each interval training session immediately after the workout and 24 hours later.

4. Interview response of the rowers to the training methods in week eight.

General Hypothesis of the Study

Both training method (A) and training method (B) will improve performance in competitive rowing. Training method (A) will elicit a greater adaptive response to the

pattern of fatigue development in the last stage of competitive performance and thus to anaerobic working conditions than method (B). Method (A), therefore, is superior to method (B).

The following are specific hypotheses of the study. Method (A) produces:

Hypothesis 1: Greater improvement in work performance.

Hypothesis 2: Greater improvement in total oxygen debt in the collection period of the study.

Hypothesis 3: Greater improvement in the fast component of the oxygen debt curve.

Hypothesis 4: Greater improvement in the slow component of the oxygen debt curve.

Hypothesis 5: Higher state of tiredness felt immediately after the interval training session.

Hypothesis 6: Higher state of tiredness still felt 24 hours after the interval training session.

Justification of the Problem

It is possible to work out a system of preparing top athletes for competition which is not deliberately based on physiological concepts. The success of such a system would depend on the practices and experiences of the coach. The training experience is related to the achievements in competition. The results in competitions become an indication of what was done and how it was done in training. Thus, the intuitive or logical approaches

to devising training programs have been quite successful in training athletes since the feedback in the form of performance and feelings of athletes provides an instantaneous and most useful kind of interaction between the athlete and the coach and permits adjustment in training.

The universal acceptance of a traditional approach to training by this method may, however, take a great deal of time and this could be reduced greatly by a more scientific approach. This study is an example of such a scientific approach designed to gauge the effectiveness of a new approach to anaerobic training of competitive rowers in the late season of preparation for competition.

Success in rowing, where hard effort must be sustained over approximately six minutes, requires the capacity to accommodate a large oxygen debt. Indeed this is probably the critical factor in the last stages of a race between crews of equal skills.

The method of training to be evaluated in this study should elicit a greater adaptive response to the pattern of fatigue development in the last stages of performance and thus to anaerobic working conditions than the conventional methods previously tried. If the rowers can adjust to it and also maintain morale, there will have been added, at least tentatively, a very useful and valuable training procedure in the preparation of competitive rowers.

Delimitations

The sample of this study is restricted only to eight members of UBC's varsity eight which was broken down into two coxed fours for the purpose of this experiment. The training program involves six workouts per week over a period of eight weeks.

Limitations

Statistical. 1. Only two coxed fours (eight subjects) are being studied. 2. There is no random selection of the subjects in that this study involves a select group of athletes.

Methodological. 1. The members of the two fours were arbitrarily assigned to a particular four crew many months prior to the experiment on the basis of their rowing technique.

Assumptions

1. Any training by the subjects during the experimental period will be confined to participation in the experimental programs.
2. All subjects have a desire to improve their rowing performance to its maximum possible level during the experimental period.
3. Rowing on the rowing ergometer is a true reflection of the rowing in a racing shell.
4. Subjects will row to complete exhaustion in testing conditions.

Definitions

Competitive rowing. This refers to collegiate races on the West Coast.

Interval training program. This is a system of conditioning rowers in which the rowers are subjected to short repeated periods of work stress interspersed with periods of relief. It involves five variable factors, including: 1. the distance of the training rows, 2. the number of repetitions, 3. the speed of the training rows, 4. the type of activity during the recovery period, 5. the duration of recovery period after each workbout. The variable factors in this study are 2, 3, and 5.

Recovery period. This marks the time period between workbouts. In this experiment it is designed to vary from two to eight minutes in each interval training workout under both training methods. Recovery period of six to eight minutes' duration implies restoration or return to a relatively normal resting state following exercise. Recovery period of two to four minutes implies only partial restoration following exercise.

Progressively shorter recovery periods. The duration of recovery period after each (or several) workbouts is progressively shortened in the same workout from eight to two minutes.

Progressively longer recovery periods. The duration of recovery period after each (or several) workbouts in the

same workout is progressively lengthened from two to eight minutes.

Workbout. This is an all-out row over 560 metres. It involves approximately two minutes of rowing in a coxed four event.

Oxygen debt. In this study, it is the amount of oxygen required in the post-exercise recovery period of 15 minutes over the total quantity of oxygen which would have been consumed during same rest period. It is considered to be sufficiently highly correlated with the oxygen debt capacity of the oarsmen so as to represent that capacity for the purpose of this study.

Work performance. The total maximum number of revolutions of the fly-wheel a rower can achieve in a six-minute all-out row on the rowing ergometer.

CHAPTER II

REVIEW OF RELATED LITERATURE

Scientific and Empirical Aspects of Modern Training Methods

A thorough review of literature pertaining to this study revealed no experiment similar to that described in this study, i.e. involving a longitudinal investigation of the effects of different types of interval training upon the performance of rowers on a rowing ergometer and on oxygen debt tolerance.

There is only a small amount of scientific research dealing directly with interval training methods. Most of the information which was uncovered dealt with interval training in track and field conducted in field situations by famous coaches. Only a few studies dealt with interval training as applied to rowing.

The review of literature about interval training has been organized into the following areas:

Scientific research of interval training;

Empirical research of interval training in track and field; and

Empirical research of interval training in rowing.

The literature about oxygen consumption in recovery period has been compiled under the following headings:

Oxygen consumption pattern in man following an exercise;

The nature of recovery oxygen curves and individual differences; and

Training effect of oxygen consumption in recovery.

Scientific Research of Interval Training

On the basis of the results of his experiments with continuous and intermittent work on the bicycle, Astrand (6) concluded that the longer the work periods the more exhausting appeared the work, even though the rest periods were correspondingly increased. Working continuously without any rest periods, the subject could only tolerate a given high work load for nine minutes, at the end of which he was completely exhausted. The subject could not complete the required amount of work of 64,800 kpm. If, instead, he interrupted the work with frequent rest periods, the subject completed the required amount of work with moderate exertion. The results of his study are summarised in Table 1.

Table 1

Data on One Subject Performing 64,800 kpm on a Bicycle Ergometer within 1 hour with Different Procedures

Type of exercise		O_2 uptake 1/hr	O_2 uptake 1/min	Pulmon. ventil. 1/min	Heart rate, beats/min	Blood lactic acid, mg/100 ml
Continuous 2160 kpm/min*			4.60	124	190	150
Intermittent 2160 kpm/min						
Work	Rest					
1/2 min	1/2 min	154	2.90+	63+	150	20
1	1	152	2.93+	65+	167	45
2	2	160	4.40	95	178	95
3	3	163	4.60	107	188	120

*Could only be performed for 9 minutes.
+Measured during 1/2 minute.

Source: I. Astrand et al., 1960.

Christensen et al. (11) and Hollman (49) reported similar results. Hollman experimented on a treadmill ergometer where two or more attempts were made with different loads for different durations, interspersed with varying periods of rest. The O_2 uptake during the work and rest were registered. In similar experiments on the bicycle ergometer, the lactic and pyruvic acid levels in the venous blood were determined. Oxygen uptake in work of average intensity, interrupted by short pauses was less than in work of the same intensity, but performed continuously. Interval

work could be done with less accumulation of lactic acid than work done continuously.

Fox's et al. (28) results agree with Hollman's investigations:

> The results showed that during interval running, blood lactic acid accumulation and the lactic acid oxygen debt were always much lower than when the same total amount of work was performed continuously. Consequently, by running in intervals more work could be performed before lactic acid accumulated to exhaustive levels.

According to Hollman (50), the favorable function of interval training is the result of the following physiological facts:

> During the loading phase the reserve capillaries in the musculature are opened, the heart beat and heart stroke volume as well as the minute volume of ventilation are increased.

Then the activity is stopped and the recovery phase sets in:

> The main part of the recovery falls within the 1 - 2 minutes of recovery during which, on the average, 60 - 80 percent of the recovery takes place . . . depending on . . . intensity . . . duration of work.

When at least three quarters of the recovery has been completed and the new loading is resumed,

> . . . the heart, circulation and respiration are then still adapted to the work, i.e. the heart beat is still high, the stroke volume still increased and the reserve capillaries are still open. Consequently, the new work (second load) can be resumed aerobically almost immediately. What is more, the lactic acid level in the arterial blood remains relatively low.

Low lactic acid level in the arterial blood corresponds with little fatigue (28) which would permit an athlete a larger dosage of work. For the required training effect, however, the total amount of work done plays an important role (1, 3, 7, 27). Equally important is continuous alternating of loading and unloading which stimulates the organism in higher adaptations, thereby forcing the organism to optimal development (7, 49).

Hollman's results and explanations are substantiated by investigations by a group of scientists from Freiburg (Reindell et al. [79], Gerschler [30], Roskam et al. [81]) in connection with the heart and interval training. They established that in the course of training according to the principles of interval training lasting not even a full two months, the heart volume was increased by more than 100 ccm., a result which until then normally took several months and even years to achieve. Reindell explains this as follows:

> The vigorously pumping heart is outwitted by the short pause, and induced to transport the full volume of blood through the still open peripheral arteries, thus retaining the stimulus on the heart while the skeletal musculature is recovering. In this way, too, the cardiac muscle receives more training than in the continuous form of endurance training. (79)

The numerous stimuli to which the heart is subjected in a brief period of time results in a strong development of the heart in a much shorter time than is possible in any other method of training.

Freiburg's group of scientists (30, 78, 79, 81) advanced the thesis that every demand which should evoke an optimum development of endurance has to be accomplished according to the rule of pulse frequency. This law of pulse frequency states that the demand on the organism must be high enough for the pulse to rise to 180 beats per minute. The rest must be long enough for the pulse rate to drop to 120 beats per minute. Gerschler (30) further indicated that this rate lasted in most cases for only five seconds after exercise, sometimes ten seconds, but never fifteen seconds, and suggested that this should be a positive consideration when planning the interval training intensity, adding that neither the distance covered, be it 100, 200, 400 metres etc., nor the number of repetition runs modified the frequency.

Earlier, Muller (70) and Lehmann (61) had already discovered the importance of pauses or intervals in "Arbeitsphysiologie". In labor investigations in which the production and pulse rate were taken as criteria, an optimum working time and the length of rest period had been established. Their investigation revealed that short pauses are highly superior since the process of recovery takes place in the shape of an exponential curve so that the greatest part of the recovery takes place during the first two minutes after the completion of the work.

In summary, then, the athlete is able to maintain the highest work load for longer period of time only if activity intervals are interrupted with frequent rest periods. The numerous stimuli to which the athlete is subjected in a brief period of time result in a strong development of his muscle strength in a much shorter time than is possible in any other method of training. On the other hand, a training of the oxygen-transporting system will be more effective if the exercise periods are prolonged to at least two to three minutes, followed by rest periods. This type of work would also adapt the tissues to high lactate concentrations, providing the exercise is severe. The controlled recovery phase is the key to strengthening the heart and so improving endurance markedly.

Empirical Research of Interval Training in Track and Field

Zatopek (98), running as much as 60 times 400 metres with a 200 metres recovery jog at times in his training sessions, astonished the world with the simplicity and intensity of his workouts. In due course, it became customary to speak of the Zatopek method which eventually became what is today known as Interval Training.

However, interval training becomes much more complex if all possible training stimuli of this method are taken into consideration. According to Nett (73), there are five possible training stimuli:

1. Distance of runs.
2. Intensity or speed of runs.
3. Number of stimuli - number of dashes
4. Duration of recovery stimuli.
5. Nature of recovery phase.

Obviously, hundreds of these combinations are possible and, as Doherty (17) put it,

> It will be quickly seen that each of these elements can be stressed or lessened, fixed or varied in accordance with the ability of each runner or with the particular view of the coach.

However, empirical research has concentrated mostly on three main factors to be considered when compiling an interval training schedule:

1. The intensity of the demand.
2. The duration of rest phase.
3. The number of repetitions.

<u>The intensity of the demand</u>. Down (19) interprets interval training in this manner:

> With better speed the objective is on quality of performance and not on quantity. It is not what one does, but how one does it . . . Establish present speed and make his objective an improvement on that . . . .

Lucas (62) quotes Percival as saying:

> The repetitions of the distances shorter than the event for which the athlete is training at a pace a little faster than or the same as the race pace objective, is the fastest and most effective way to develop endurance.

Doherty's (18) interpretation of interval training places the emphasis on the goal a runner hopes to obtain at the end of

the season. He bases his variables in the following manner:

1. One-half the racing time or pace - endurance training. The fixed variables are distance, pace, and rest period with the number of repetitions being varied.

2. One-fourth the racing time or speed - endurance training. The fixed variables are distance, rest and the number of repetitions, with pace being changed.

Igloi (69) introduced sets or series of short, intense repetitions of running. The running of sets of repetitions over short distances at high speeds enabled Igloi's athletes to achieve excellent competitive results over a wide variety of distances.

According to Ozolin (77), the running pace in interval training should be faster than race pace, but not the maximum, if special endurance is to be developed.[1] Ozolin (77) also reports the failure of Pugachevski to improve significantly the times of his athletes when trained at all-out effort.

Laboratory and field experiments with 800 metre runners were conducted by Elfimov (21). His results in Table 2 show that the greatest increases in working capacity were attained by the groups which trained at a faster than race pace, but not at all-out effort. The exercise used was running in place.

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[1]Special endurance is the endurance necessary for the particular event.

Table 2

Results of Elfimov's Experiment

Test group	Training pace steps/min	Duration of run to limit at pace of 230 steps/min Prior to training	Post training	% increase in work capacity
1	230	52.3 sec	72.3 sec	38.3
2	300	52.0 sec	98.6 sec	89.6
3	260	54.3 sec	106.3 sec	95.8

Stampfl (88) would increase the speed of running only after sufficient mileage was covered at a slower than competitive pace. Jewkes (56) expressed similar belief:

> When the athlete has got used to the volume of work, the number of fast intervals should be gradually reduced while the speed is increased.

Zatopek (98), on the contrary, expressed the opinion that better results were obtained by more volume and slower intervals. Roskamm, Reindell and Keul (81), too, promote the improvement of muscle stamina or endurance through very numerous repetitions of contractions with sub-maximum effort. Low speed is direct prerequisite of effectiveness of the interval training method on heart stimulation in the recovery as stated by Freiburg's law of pulse frequency (30, 79, 81).

On the basis of the results of his field work, Nett (72, 73, 74), who has been a great follower of

Freiburg school of training, came to the conclusion that slow pace and short distances up to 200 metres, as required by Gerschler and Reindell, are not sufficient in training athletes for competitions successfully. In addition to "classical" interval training, he introduces tempo running which requires faster than racing pace and extends up to 1,000 metres and, occasionally, more. He admits that tempo running which is essentially interval type of training,

> . . . does not permit - as we have seen - any specific effect upon the heart because of the absence of increase in the beat-volume during recovery. Hence its effect on the metabolism adaptation of the heart remains limited. (72)

However, a faster tempo is necessary for muscle adaptation. The high speed is the real stimulus on the muscular system and its metabolism (19, 74). Nocker (76) believes that the muscles' increased capacity for prolonged effort is closely related with the potassium content in the muscles. The more exhaustive is the work the lower the potassium content. After absolutely exhausting work, the potassium content is considerably lower in the trained muscle than in the untrained muscle. It is, therefore, essential

> . . . that the stimuli (speeds) are strong enough . . . that lead to the emptying of the potassium battery and constitute a sufficient stimulus so that during the resting-phase a re-charge is made possible which exceeds the original potential . . . on the basis of this . . . the muscular system generally requires the time to be longer and the stimuli to be in greater doses (higher speeds) than is necessary for the process of conditioning the circulation system. I recommend days with faster runs. (76)

Astrand (7) fully agrees with Nocker:

> . . . A training that is prolonged to at least two minutes . . . would adapt the tissue to high lactate concentrations[1] providing the exercise is severe.

The next step in the development of modern training methods is the appearance of the New Zealand runners trained by Lydiard. Lydiard (63) ascribed his success to marathon training.[2] However, the closer Lydiard came to the racing season, the shorter were the demands placed on his runners and the faster were the speeds required of them.

The duration of the rest phase. By keeping the rest heart stroke volume up at a rate of 120 beats per minute, according to Freiburg school (30, 79, 81), the heart is induced to transport a large volume of blood through the arterial system, whose capillary network remains continuously dilated. This, as Hollman (49, 50) also confirmed, maintains the stimulus on the heart while the skeletal musculature was recovering, so enabling the next effort to be resumed aerobically with the level of the lactic acid relatively low. Thus the favorable function of interval training is while the athlete is resting. However, the rest phase should not exceed 90 seconds. If in the course of the daily workout the pulse at the end of the pause, as compared with 120 at

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[1]Which Astrand relates to oxygen debt requirement.

[2]Marathon training would involve a steady state running at a reduced effort for long periods of time.

the beginning of the workout is substantially increased, the workout must be terminated.

Nett (73) deduced the following practical basic principles:

1. Duration of the pause should be 45 - 90 seconds.

2. Duration of the individual exertion (run) one minute at the most.

3. Intensity of the individual exertion should be such as to produce a pulse frequency of 120 to 140 at the end of the pause.

However, in tempo running, Nett (74) advocates somewhat longer rest pauses:

> The speed and distance chosen in tempo running decides (by the degree of excess acidization) . . . the duration of the recovery pauses.

Similarly, Nocker (76) advocated computing one-third of the difference between the pulse at rest and the pulse during exertion, and subtracting the quotient from the maximum pulse rate during exercise. Nocker claimed that this was the figure at which, after a sudden drop, the heart rate tends to stabilize and was the point at which the next effort should be begun.

According to Diem (15), the recovery must last only until the breathing and the heart are calm again and a feeling of freshness is felt. Immediately after that, the work (activity) must be resumed so that the athlete does not get unaccustomed to strenuous work, i.e. before he has completely recovered.

Down (19) concluded that whichever authority one was prepared to accept, it was apparent that the critical range was from 120 - 180 heart beats per minute. To claim a more precise threshold was surely presumptuous.

Zatopek (98) used a standard 200 metre recovery jog which lasted up to one minute. A few years later, Kuts (101) who broke Zatopek's records, repeated Zatopek's workouts. However, the intensity of his runs was somewhat greater and the duration of his recovery was shorter.

Laboratory and track experiments with 800 metre runners were conducted by Elfimov and Ozolin (22, 77). When the test runners were doing 400 metre repetitions, it was noted that the second repetition was usually slower than the first. They found that in order to run identical times for the first two repetitions, 15 to 20 minute rest was necessary. With three minutes' rest the second 400 metres were about seven seconds slower than the first. This gap decreased to about zero second for 15 to 20 minute rest, but taking more than 20 minutes also produced a slower and slower second 400 metre run. Additional tests by Elfimov (21) with two groups of 800 metre runners, each of whom did 20 training sessions of repetitious running, showed that the group taking 20 minutes rest between repetitions improved their 800 metre time by 4.5 to 5.1 seconds, whereas a second group taking seven minutes rest improved by only 2.1 to 2.5 seconds.

The number of repetitions. As a general rule instructs Nett (75) the total volume for each workout may be two or three times actual racing distance, exclusive of warmup and recovery or slow running. However, mature runners of international calibre recognize no such boundaries and frequently put in far more total running volume each workout over a prolonged training period (98, 101). Stampfl (88) also recommended numerous repetitions at a slower than racing speed which would far exceede the actual racing distance.

Mole (68) in his study of the influence of number of repetitions in interval training on the aerobic metabolism and endurance performance of four young men indicated that aerobic metabolism, running efficiency, endurance performance, and oxygen requirement for the all-out treadmill run tended to improve as the total workout increased.

On the contrary, Leclerq (60) stated that every repetition of effort after the sixth is questionable as regards the efficiency of training adaptation. Ozolin (77) believes that the total sum of the fast stratches should be more than one and one-half to two times as much as the athlete's racing distance.

It can be concluded that the subject is both vast and controversial as far as the intensity, duration of rest and the number of repetitions are concerned. Some coaches and scientists (98, 68, 75, 88, 101) believe that the best

results accrue from a great number of comparatively slow intervals. Another (60, 77) prefers a smaller number of intervals performed at a speed very much faster than racing pace. Still another (69) believes in all-out efforts only. The most recognized authorities are of the opinion that the intensity of the demand should eventually be faster than the target racing speed.

No exact scientific means has yet proven fully successful in computing the correct recovery period for each individual in the various types of interval training. Whatever the length or activity during the recovery period, it is evident that coaches work on the concept of partial recovery. The recovery period is short enough so that athlete never recovers completely. However, as the athlete becomes more fit, the time needed for adequate recovery decreases. There is no sufficient uniform evidence to yield any strict rule for assessing the number of repetition runs. The only conclusion that could be made is that the total length of fast runs in a workout should exceed the length of the racing distance.

Hollman (49), however, made an important observation. This was that the necessary prerequisite for the success in his research was that the duration of work, the intensity of work and the length of the rest pause were in relation to one another according to what was optimal for the subject. He also proved that every subject had an individual optimum. Thus, individual differences must always be taken into

account in compiling an interval training program (99). What is even more important, according to many leading coaches and former first class runners, is the optimum mixture of different training methods. The trend in modern training today seems to be the complex training (17, 18, 63, 72, 88).

Empirical Research in Interval Training in Rowing

In trying to apply the principle of interval training to rowing in 1950, Adam (1) was confronted with unlimited flexibility of the method. Namely, the problem is the one of organization of the variable factors of interval training as to obtain the best effect with the least investment of time and effort in training. In trying to realize this aim, Adam came up with a form of training which has become rather widespread in rowing. This is called stroke play and consists of a regular change in the demands made on the oarsmen, i.e., the demand between sprint and racing strokes and rest periods. The characteristic form of this exercise was 10-10-10. After the team had warmed up, there were ten sprinting strokes or spurt strokes, ten racing strokes, and ten spurt strokes and thirty light or rest strokes. According to Adam, the team should achieve

> . . . its maximum speed. The racing strokes should be executed as if the team were going through a two thousand metre course in the best possible time with an even tempo. The light strokes should remain

> technically precise, full-length strokes . . . the application of power should be reduced greatly. (1)

This stroke play was further developed by the inclusion of longer times during which demands were made on the organism. Thus the training intervals 10-20-10, 10-30-10, or 100 power strokes of 40-20-40 with the spurt strokes in the middle are often used. However, the number of rest strokes will never be greater than 35 strokes. The total demand per unit of training in this fashion is four to six hundred strong strokes.

In addition to stroke play, a second form of interval training, tempo training, based on an entirely different consideration, was developed by Adam (2, 4).

> Since the two thousand metre stretch should be accomplished with as even pacing as possible, it is extremely important that each team knows which speed it can maintain for two thousand metres . . . . There is a simple rule that a speed which can be repeated over a distance of 500 to 600 metres, five or six times with little variation, is satisfactory. This speed can be maintained constantly in racing. . . . The team should go through these 500 or 600 metre distances twice; the speed they are to reach is racing, then increase the number of repetitions to six or eight.

Using these two interval training methods, Adam came to the following interesting observation:

> If we used exclusively stroke play, we noticed a very rapid development in the performance of the circulatory system, but no increase in the local muscular endurance . . . . If we added tempo training, this condition was eliminated. (2)

Adam's stroke play training corresponded very closely to

Freiburg's pulse frequency law which places a very high effect on the circulatory system. However, different kinds of demands - tempo training - must be made on the organism in order to improve local muscular endurance. This notion would agree with Nett (72) and other coaches who advocated longer stretches at racing speed.

Robertson (80)[1] of New Zealand incorporated Lydiard's training methods and believes that long distance rowing creates a firm basis on which, with special interval training over short distances, he achieves an ability to work at high speeds for short periods of time.

Similarly, Harre (36) indicates that the human body possesses capacities which are best developed under demands of long duration. Consequently, East German rowing team covers 20 to 30 kilometres two or three times a day at a steady state and only some distance is rowed at a racing speed.

Harre (36) extends the number of variables of interval training to seven as adopted to the needs in rowing.

1. The duration of demands on the organism.
2. The intensity of the demands on the organism.
3. The number of strokes per minute.
4. The length of the pause between these demands.

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[1]New Zealand National Coach for Olympic Rowing Team.

5. Intensity of the demands during the pause.

6. The number of repetitions.

7. The total amount of interval training in one's total training program.

He believes that interval training is the most versatile method of training which could be adopted by young and old, women and men alike, and could be varied according to the future goals in performance, technical abilities of the oarsmen and their specific psychological need and physical abilities of the particular crew.

All three main training methods: interval, long distance steady state and complex, as established in three leading rowing nations - West and East Germany and New Zealand - had bearings on the development of the Russian rowing program. In one-year cycles, the Russian school is trying to incorporate the main ingredients of all three methods in preparation of their senior oarsmen for top competitions.

In conclusion, it could be said that in an attempt to improve the performance of rowing crews, the authorities of the leading rowing nations accepted the principles of interval training method as developed and advanced by the track athletes, particularly for middle and long distance runners.

Oxygen Consumption Pattern in Man Following an Exercise

The first physiologists to study the changes in

respiration at the transition from work to rest in man were Krogh and Lindhard (59). They observed a marked change in oxygen consumption rate after the first few minutes. There was an initial short period of rapid decline of the oxygen consumption, followed by a long period of slow recovery. It remained for Hill and associates (29, 47, 48) to term this system of "paying back" oxygen that was apparently not available at the time needed, as "oxygen debt". After severe exercise

> . . . the initial phase of recovery is rapid, but a prolonged process supervenes which may take as much as 80 minutes to reach completion . . . . There are clearly two factors at work . . . the initial rapid fall in the oxygen intake on the cessation of exercise, the other for the prolonged remainder of recovery occurring after extended or severe exertion. (47)

Hill and colleagues were aware of the fast component, but at that time thought it to be a rapid phase of the lactic debt:

> We may conclude, therefore, that the first and rapid phase of recovery is nothing more than oxidative removal of lactic acid in the muscles where it was formed . . . . The second and prolonged phase, on the other hand, represents the oxidative removal of lactic acid which has had time to escape by diffusion from the muscles where it was formed. (47)

As for the nature of the payment of the oxygen debt, Hill observes that

> . . . each process is exponential in character - one is rapid; one, however, is slow. Moderate exercise is followed to a preponderant degree by recovery of the rapid type. (47)

Margaria, Edwards and Dill (66) have reported fractionation of the post-work oxygen consumption into a rapid pay-off component that occurs as a result of either light or heavy work, and a slow pay-off lactic component, previously discovered by Hill in 1924, that is not ordinarily observed unless heavy muscular work has occurred. Among their findings was the observation that there was no increase of lactic acid in the blood accompanying the oxygen debts after exercise until a subject worked at an intensity corresponding to two-thirds maximal oxygen consumption. As a result of this observation, the term "alactacid debt" was introduced.

> . . . because it takes place without apparent extra lactic acid formation . . . . This alactacid mechanism of paying an oxygen debt is much more convenient than the lactacid mechanism as far as speed of payment is concerned. This speed is 30 times greater, taking only half a minute to pay 50% of the alactacid debt, while the payment is practically complete (98.5%) in three minutes. (66)

In another study, Margaria et al. (67) repeated similar observations as noted in the earlier study (66). In addition, there was no observable removal of lactic acid at the beginning of recovery. To them, this indicated that there was a fraction of the oxygen debt that was not related to the lactic acid mechanism. Berg (10), Eskildsen (24) and Wells et al. (95) confirmed these findings by Margaria.

Huckabee's work in the late fifties is in direct conflict with the above concept of an anaerobic threshold. In a series of studies (51, 52, 54, 55), Huckabee challenged the concepts of Hill et al. (47, 48) and Margaria et al. (66) which related the oxygen debt of exercise to changes in blood lactate concentration. He developed a formula based on the lactate and pyruvate measurements. The calculation obtained related changes in lactate concentration to pyruvate metabolism and was termed "excess lactate" which, according to Huckabee, should be directly related to tissue hypoxia and, therefore, oxygen debt (51, 54).

$$\text{Excess lactate} = (L_n - L_o) - (P_n - P_o) \times L_o/P_o \qquad (1)$$

where L_o and P_o are equal to the resting arterial blood lactate and pyruvate concentration, respectively, and L_n and P_n are the same determinations during exercise. Furthermore, from the physiological significance Huckabee attached to excess lactate, he concluded that the metabolic alterations responsible for oxygen debt formation were essentially similar at all grades of exercise (51). If he calculated the quantity of oxygen necessary to convert the peak excess lactate back to pyruvate, he found close approximation to the measured oxygen debt.

He found excess lactate at low levels of work with small oxygen debts, and the close approximation still held true (54). Little or no total lactate had been found at these levels by other investigations (66, 67).

On the basis of his research, Huckabee denied the existence of an alactacid oxygen debt or an alactacid portion of a large oxygen debt. He forwarded the thesis that virtually the entire debt could be accounted for at all levels of work with lactic acid, specifically excess lactate.

Subsequent research by Knuttgen (58), Thomas et al. (92), Astrand (7) and Wasserman et al. (93, 94) and Naimark (71) reported that below a specific work load (anaerobic threshold) in normal subjects, there is a cardiorespiratory reserve and increase in arterial blood lactate does not occur until the energy requirement is about four times basal. This is in agreement with studies on blood lactate during exercise done by others (58, 66, 67, 95).

Margaria et al. (65) also reinvestigated the kinetics of oxygen debt formation and were unable to agree with Huckabee's interpretation of the significance of excess lactate. The experiment confirmed the delayed process of lactic acid formation as found earlier by Margaria et al. (66, 67) and others (58, 95), and

> . . . an exergonic anaerobic process, which is not lactic acid formation, must take place at the beginning of exercise; this is the contraction of the alactacid oxygen debt. (65)

The combined research is shown in Figure 1.

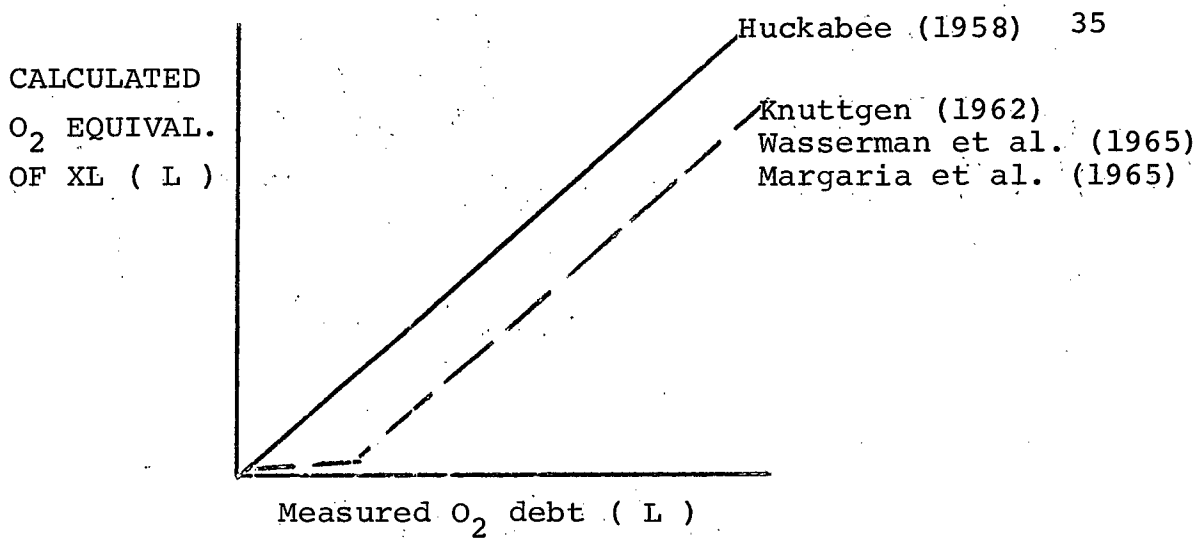

Figure 1

Comparison of Measured Oxygen Debt to Calculate Equivalents of Excess Lactate (Oxygen Necessary for Conversion to Pyruvate)

As was stated, Huckabee (51, 54) could account in its entirety for any oxygen equivalents of excess lactate.[1] Therefore, the rectlinear relationship resulted. Later research (65, 71, 92, 93) failed to find any relationship with excess lactate until a debt of between one and one-half and two liters was attained. There was then a parallel increase which always underestimated the total debt by about the same amount throughout the entire range. These data would, therefore, support Margaria's concept of an alactacid portion of the debt. The concept of a linear increase in excess lactate and oxygen debt as a function of total metabolic rate has also been attacked by Harris et al. (39), Thomas et al. (92) and Wasserman et al. (93).

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[1]The oxygen necessary to convert hypoxic lactate to pyruvate.

To confuse the subject more still, Harris et al. (39, 40) and Thomas et al. (91) obtained different results when they measured the rate of increase of excess lactate during exercise. In contrast to the linear increase of excess lactate with time described by Huckabee, they observed that excess lactate plateaus and even decreases. In a later study, Harris observed again excess lactate rise and fall, rather like that for lactate itself and can become negative while exercise is proceeding (38).

In summary, then, research clearly shows the attempt of physiologists to link the concentration of lactate in the blood causatively with the oxygen uptake after exercise. The present situation on the subject looks like this:

1. Margaria, Edwards and Dill found an alactacid portion of oxygen debt (66, 67).
2. Huckabee denied its existence (51, 54).
3. More recent papers confirmed not only an alactacid portion, but a lactate portion as well (65, 93).
4. Harris and Alpert believe the possibility that the concentration of lactate in blood does not in any way determine the magnitude of the recovery volume of oxygen (5, 39, 40).

The Nature of Recovery Oxygen Curves and Individual Differences

Hill et al. (47) first pointed out that recovery curves for oxygen consumption are exponential, which has subsequently

been confirmed by other investigators (10, 65, 66, 67). According to Hill and Margaria et al. (66), the oxygen recovery curve after strenuous exercise is composed of two exponential curves, an initial rapid component lasting a few minutes, and a longer component of several hours' duration depending upon the exercise intensity. After moderate exercise, the recovery curve is composed entirely of the first component (alactacid) and can be represented by a theoretical exponential expression

$$A = A_o e^{-Kt} \tag{2}$$

Margaria et al. (66) as well as others (42, 45) have found that the lactic component of the total oxygen debt of heavy exercise can be described by the same formula. Thus, the expression 1 becomes

$$A = A_1 e^{-K_1 t} + A_2 e^{-K_2 t} \tag{3}$$

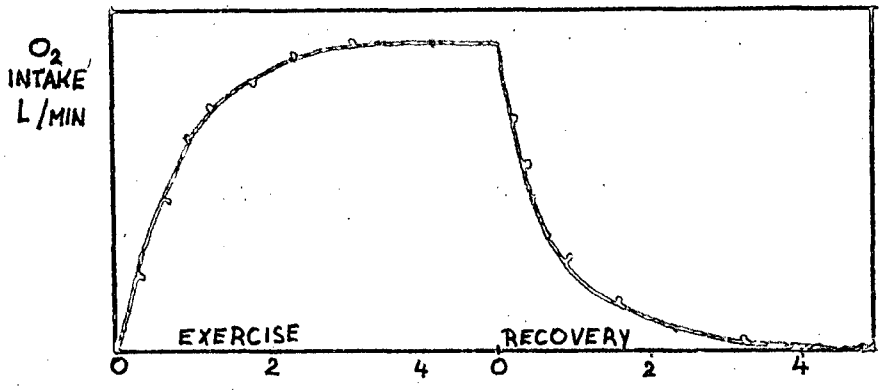

Figure 2

Exercise and Recovery Curves; Experimental Points Represent Average of 12 Subjects Measured at Lightest Bicycle Work Load by the Closed-Circuit Method. Recovery Portion of the Curve was calculated from Formula 2 (42:430)

A_o in formula 2 represents the rate of oxygen intake at the cessation of exercise and K represents the velocity constant of the recovery curve. Velocity constant K, according to Henry (42), is not related to the rate of work at submaximal exercise and Berg (10) as well as others have indeed found it to be independent. Thus, if K remains constant at varying work loads for a particular individual, the size of the debt will be determined by the steady state oxygen income during exercise which is showing a linear relation with the rate of work up to the point where limitations of oxygen supply to the working muscles came into action (42). Hence, the oxygen debt should also approximate a simple linear function of the rate of mild or moderate work.

At moderate work load, then, A_o, which is oxygen intake at zero time of the recovery, assumes the value of oxygen income at steady state during exercise. Since there are individual differences in the oxygen requirements for the same external work of mild or moderate degree, there should be a relatively high correlation between A_o (but not K) and the total metabolic cost of the work (42).

In the two-component exponential system, formula 3, the rate of oxygen intake at minute t of recovery is specified by $A_1e^{-K_1t} + A_2e^{-K_2t}$, with $A_o = A_1 + A_2$. The first term represents the alactacid component of oxygen debt, with A_1 and K_1 standing for the rate of alactacid oxygen

consumption in recovery and alactacid velocity or time constant, respectively. The second term of the function represents the lactic component of oxygen debt, with A_2 and K_2 standing for the rate of lactic oxygen consumption in recovery and lactic velocity or time constant, respectively (10, 14, 45, 46, 66).

Berg (10) has proved that there are individual differences in the alactic velocity constant K_1. De Moor (14) studied the possible sex differences in velocity constants. Twenty-two men and 21 women performed a submaximal exercise on an electric bicycle ergometer with the speed held constant. Oxygen consumption was measured and individual two-component exponential recovery curves were treated statistically with reference to mechanical efficiency and sex differences. It was observed that alactic oxygen debts and A_1 and K_1 curve constants were not related to mechanical efficiency. Less efficient men and women have a larger lactate debt component, a larger proportion of lactate debt in the total debt, a higher A_2, and a slower K_2. Men have a faster alactic velocity constant K_1 than women. There is no sex difference in the lactate debt velocity constant K_2 or in the amount of either alactic debt or lactate debt.

Berg mentioned age factor as a possible influence on the rate of recovery. In his study (10) there was a

correlation between K_1 and age, due mainly to the fast K_1's of the youngest subjects and slow K_1's of the oldest subjects. The age range was 18 - 68 years. Within the age range 20 - 40, there was no appreciable correlation.

Training Effect of Oxygen Consumption in Recovery

Berg (10) has presented suggestive evidence that the individual differences in the velocity constants K are related to the efficiency of the circulation in delivering oxygen to the tissues, even in moderate exercise. This indicates that changes produced in the individual in the direction of improved oxygen supply to the tissues should leave steady state intake A rate unchanged if the work is unchanged, but velocity constant K should increase and the size of the debt should decrease.

Henry and Berg (43) have shown that a typical athletic conditioning program resulted in decreasing the alactic oxygen debt resulting from a standard stool-stepping exercise, and also significantly speeded up the recovery rate. The mean A_1 of 23 athletes before conditioning was 16.1 cc/min per unit of body weight, and after conditioning, 14.9 cc. The difference, however, is not significant, since the t ratio is only 1.5. The mean K_1 before conditioning was 1.40, and after conditioning 1.52, a difference that is statistically significant above 1 percent probability level. A regime of training influenced the maximum oxygen intake

and the level of oxygen intake at which "excess lactate" starts to appear in the blood in 13 Bantu male subjects in a study by Williams et al. (96). Their results also show that these two parameters can change independently of each other. However, the finding that emerges most clearly is that for the group as a whole, the percentage increase in the level of oxygen intake at which anaerobic metabolism occurs is greater than the percentage increase in maximum oxygen intake following a training regime over four to sixteen weeks.

Since the introduction of the lactacid - alactacid concept of oxygen debt by Margaria, Edwards and Dill (66), physiologists (53, 65, 93) have attempted to relate these components to the oxygen recovery curves observed following exercise. However, much of this research has been in conflict because investigators have been unable to quantitatively separate oxygen debt into lactacid and alactacid components at work loads that have resulted in elevated blood lactate. There has been no suitable method which could be used to eliminate the involvement of lactate in oxygen debt, thus allowing one to measure only the alactacid component of an oxygen debt. As a result, there has been no universal agreement on the relationship between lactate removal and the excess oxygen consumption observed following exercise.

In view of this conflict, Barnard et al. investigated the involvement of the Cori cycle in oxygen debt. By blocking lactate removal by the liver, oxygen debt was reduced by approximately 44 percent. A reduction in oxygen consumption during the last minute of exercise was also noted. Thus, it was concluded by investigators, that the lactacid and alactacid components are involved in oxygen debt when lactate is being removed by the liver following exercise. Thus, oxygen debts measured after blocking lactate removal by the liver, are a good approximation of the alactacid oxygen debt.

In view of these findings, Barnard et al. (9) extended their research on dogs to examine the effect of training as well as various work loads on the lactacid and alactacid oxygen debt components. The data obtained from the two dogs used in the study clearly shows the effect of training on lactic acid production and, consequently, on the oxygen consumption during exercise as well as during recovery. During all the tests conducted after training,

> . . . the peak lactate values were much less than those observed prior to training. This was even true at the higher workloads studied after training. The lactate concentration also returned to the resting level much sooner after training. (9)

The above findings agree with earlier works of Crescitelli and Taylor (13).

Since lactate accumulation was decreased as a result of training one would naturally expect the oxygen debts to be decreased. This was in fact the case even at much higher work loads studied after training. Oxygen debts for the two dogs at the heavy work load (6.5 mph, 20% grade) after training were reduced by 44.6 and 54.5 percent from the nontrained debts at four mph, 20 percent grade.

These findings from Barnard et. al. substantiate previous observations by Baldwin (8) and by Henry and Berg (43) who have also reported a significant decrease in oxygen debt as a result of conditioning programs.

Barnard could not draw any definite conclusions regarding changes in the alactacid debt with training. However, the data obtained for one dog offered some indication that training did not significantly change the alactacid oxygen debt.

In conclusion, then, it seems highly possible that trained individuals and animals give lower blood lactate responses and they may also have a greater capacity to utilize lactate once it accumulates in the blood. Therefore, if less lactate is being formed and more is capable of being utilized by other tissue in addition to that removed by the liver, less lactate remains to be converted back to sugar. As a result, the oxygen consumption needed by the organism would be decreased during work and recovery. The observations made in the literature suggest, then, that these

adaptations are occurring as a consequence of training.

CHAPTER III

METHODS AND PROCEDURES

Introduction

Eight varsity rowers were divided into two equally fast "four-oar" crews (A and B) and assigned to two interval training programs in the late stages of preparation for the 1972 competitive season. The training lasted eight weeks. The rowers were tested on a rowing ergometer at the beginning, half way through, and at the end of the experimental period. Total work completed and recovery oxygen intake data were analyzed statistically to determine the differences.

Subjects

The subjects (S) of the study were crew members of the varsity eight at the University of British Columbia. It is important to note that the subjects represent a group of highly motivated, elite athletes who had been in rogorous training for the Olympics six months prior to the experimental period. In the two seasons prior to the testing, they were Canadian Champions and represented Canada in World and Pan American Championships. These oarsmen were dedicated and did their best when asked for a maximal effort. This co-operation was an absolute necessity for the rowing ergometer testing part of the study.

The eight oarsmen had been changed around for some time prior to the experimental period with the purpose of attaining two equally fast crews at the beginning of the experimental training.

One of the oarsmen from crew A broke his arm at the beginning of the third week of the experimental training period and had to be replaced. Thus only seven subjects were experimentally treated in this study.

All seven subjects were single university students with an average age, height and weight of 21 years, 73 inches and 190 pounds, respectively.

The Design of the Training Programs

Two crews of four rowers plus coxwain were assigned almost similar rowing training programs which were carried out at the same time and place, under one coach. The training programs were dissimilar only in that late season anaerobic interval training for eight weeks was done with each crew using a different procedure in the recovery phase between workbouts. In addition to interval workouts, the eight-week program included steady state rowing and anaerobic fartlek rowing workouts. These were the same for both fours. All three types of workouts were organized in the following fashion:

Period I (1st, 2nd, 3rd, and 4th week)

3 workouts - steady state rowing

2 workouts - interval rowing

1 workout - anaerobic fartlek

Period II (5th, 6th, and 7th week)

3 workouts - interval rowing

2 workouts - steady state rowing

1 workout - power rowing

Period III (8th week)

4 workouts - interval rowing

2 workouts - power rowing

Interval training program A. The crew A following program A was, by the end of the experimental training period, expected to row 16 times 560 metres intervals in the following fashion:

Repetitions		Distance		Rest Period
4	x	560 m	Rest period betw. bouts	8 min
4	x	560 m	" " " "	6 min
4	x	560 m	" " " "	4 min
4	x	560 m	" " " "	2 min

Interval training program B. The crew B following program B was also expected to row 16 times 560 metres intervals but in a qualitatively different fashion from the crews following program A.

Repetitions		Distance		Rest Period
4	x	560 m	Rest period betw. bouts	2 min
4	x	560 m	" " " "	4 min
4	x	560 m	" " " "	6 min
4	x	560 m	" " " "	8 min

The rest periods in each interval training workout either shorten or lengthen, depending on the program, thus allowing the rowers to keep the same racing pace or equal times under program B and gradually slower pace or slower times under program A as the workout would approach termination.

Building up the work load in interval workouts from the "initial 4 x 560 m stage" to the "final 16 x 560 m stage" involved a gradual increase in number of repetitions from four to 16.

Design of the Testing Program

The experimental design allowed three complete testings: in addition to pre- and post-training testing, there was one complete testing half way through the experimental period. All three testings were carried out at the University of Washington. Upon arrival at the Experimental Laboratory one hour before the testing, a S was asked to rest for 15 minutes and read the instructions for testing procedure (see Appendix A).

Data collection procedure involved:

Rowing performance. The S assumed the normal rowing position on the rowing ergometer, adjusting the seat and slide assembly and foot braces to conform to his wishes. Following an additional warmup for five minutes on the ergometer, the S was then asked to do a one-minute all-out row. The number of ergs was recorded. After a short rest, the S executed a six-minute row at the maximal possible effort. Work output in terms of ergs was measured continuously throughout the six-minute exercise. Each S was required to obtain the maximal possible number of ergs at any desired stroke rating. However, stroke rating was maintained by timing and verbal assistance from an experienced coxwain, to increase motivation.

Recovery metabolism. For 15 minutes, the recovery metabolism was determined by open-circuit system. There were ten collections made: every half a minute for the first two minutes, then every minute until the fifth minute and then from minute five to seven, seven to ten, and ten to fifteen.

Subjective response to the training session. After each interval training session during the experimental period, each S completed one part of an especially designed questionnaire with fatigue scales. The second part was completed on the following morning before the workout. At the end of the experimental training period, the Ss submitted a written subjective response to the training methods.

Apparatus

Rowing ergometer. The Leichardt rowing ergometer is a ruggedly constructed piece of apparatus. It allows an operator to execute a rowing motion which simulates very closely, both kinematically and dynamically, the actual motion experienced when rowing a boat. It also permits the accurate measurement of the work output.

In the Leichardt ergometer the S has his feet in clogs and is seated on a sliding seat. He operates a handle having the same dimensions as an oar handle, and which is pivoted in the position corresponding to that of a racing shell. The handle is connected to the drive train in such a way that the S experiences the same resilience as would be experienced with a real oar. The handle is free to move not only horizontally, but vertically and can rotate about its own axis thus allowing the S to duplicate any motion on the machine that he would carry out in a boat. The energy fed in by the S is absorbed by a friction brake, acting against a heavy fly-wheel. The size and speed of the fly-wheel are such that the percentage reduction in speed between strokes corresponds closely to the percentage reduction in speed of an actual boat between strokes; also the speed with which the S has to take his catch closely approximates to that in a boat. The load applied to the fly-wheel is such as to cause about the same rate of energy dissipation as would occur due to the motion of the hull through water.

The fly-wheel brake is specially designed to maintain constant torque load over a wide range of speeds.

With the application of constant torque load it is a relatively easy matter to determine the work done by the S over a given period of time; the work output being given by the product of the load torque times the total angle turned through by the fly-wheel. The total angle is readily measured by means of a revolution counter. One revolution corresponds to one erg.

All of the rotating parts are mounted on generously sized ball bearings thus reducing unknown friction losses to a minimum. The accuracy with which the work output may be determined is to within approximately $\pm$ 1 percent of the true value; this accuracy being more than adequate to allow reasonable comparison of the potentials of various individuals. See Figure 3, page 52.

Open-circuit system equipment. The experimental S used a mouthpiece with nose clip to ensure a single directional air flow by a set of two flutter valves. The expired air was led through flexible plastic tubing of 3.5 cm i.d. into 300-liter and 180-liter Douglas-type polyvinyl chloride bags (W. E. Collins, Inc.). O_2 and CO_2 percentages were determined paramagnetically (Beckman Instruments, Model E-2) and by infrared analysis (Lira 300, Mine Safety Appliances Co.), respectively, at the University of Washington Cardiology Department by an experienced

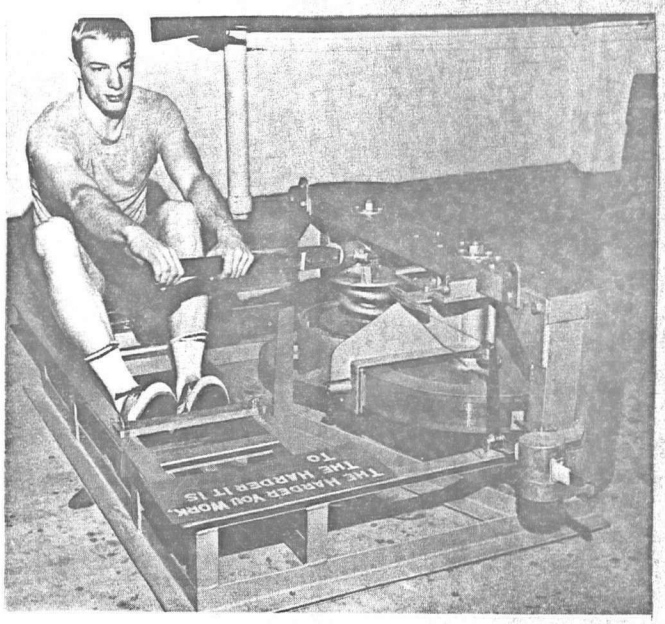

Figure 3

Testing on the Leichart Rowing Ergometer;
Front and Side Positions.

technician. Gas volumes were measured spirometrically and appropriately corrected.

Fatigue scales. The two fatigue scales as used in the questionnaire (see Appendix B) were adapted from the "Subjective Evaluation of Level of Work" scale used by Astrand and his associates. The fatigue scale used immediately after the interval training session has seven levels with four written labels of tiredness (somewhat tired, tired, very tired and completely exhausted) dispersed evenly from 1 (somewhat tired) to 7 (completely exhausted).

The second fatigue scale used includes six levels (from 0 to 5) of tiredness still felt by the Ss 24 hours after the training session. "Not at all" - 0 is followed by "very, very slightly" - 1, "slightly" - 2 and "fairly light" - 4.

Levels that are left blank accommodate any other state of tiredness not described by written label in both scales.

Testing Parameters

The three experimental testings measured the following parameters of fitness:

1. Total work performance completed in six minutes on the rowing ergometer in terms of ergs.
2. Total oxygen consumption obtained in ten collections for 15 minutes.

Subjective written responses about the state of fatigue were collected immediately after each interval training session and 24 hours later. Written responses of the Ss to the training methods were obtained at the end of the experimental period.

Statistical Analysis

A theoretical exponential function of the form $A = A_1e^{-K_1t} + A_2e^{-K_2t}$ was fitted to the observed oxygen debt pay-off values of each S by using "Non-linear Least Squares - BMD - X85" (82) computer program. Thus predicted values for each of the collection periods as well as the parameters of the fast (A_1, K_1) and slow (A_2, K_2) component of the oxygen debt were obtained. The same exponential function was also fitted to the average experimental data of all seven Ss in testing 1 and to the average experimental data for method (A) and (B) in all three testings.

Predicted and observed curves for three individuals were plotted in Figure 4 to examine goodness of fit of the mathematical exponential function to the experimental data. This was necessary in the absence of any previous experience about fitting of the above mathematical function to the data obtained after a violent all-out effort. Predicted and observed average oxygen debt curves for all Ss in testing 1 and predicted average oxygen debt curves for two methods in all three testings were plotted in Figures 5 and 6.

The parameters of oxygen intake curve in recovery were treated statistically for testing the validity of Hypotheses 3 and 4. A repeated measure analysis of variance for a 2 x 3 factorial experiment was used by employing "General Linear Hypothesis - BMD - X64" (83) computer program:

Source of Variation	Degree of Freedom
Training Method (M)	1
Subjects M ($S_W M$)	5
Testing (T)	2
M x T	2
$S_W M$ x T	10
TOTAL	20

The same analysis of variance was used in treating statistically the rowing performance and total oxygen debt for testing the validity of the General Hypothesis of the study as well as Hypotheses 1 and 2. To test the validity of Hypotheses 5 and 6, medians were calculated from the observed data on the fatigue scales from the questionnaires and compared.

All rowers were expected to improve their rowing performance as well as their total oxygen debt in recovery after an eight-week training program. Because of the supposed superiority of method A over method B the rowers

following training program A were expected to show greater improvement in these two parameters than rowers following training program B.

Any increase in the total oxygen debt will necessarily mean an increase in one or more components of the oxygen debt curve. The nature of any improvement in values of fast or slow components in rowers' oxygen debt will be reflected in improvements in A's and K's which quantitatively describe them. Testing of Hypotheses 3 and 4 (Chapter 1) was made in accordance with the theoretical basis which is outlined in the following paragraph.

The fast component of the oxygen debt curve will, for example, improve (become bigger) if:

1. A_1 increases with K_1 unchanged;
2. K_1 decreases with A_1 unchanged;
3. A_1 increases and K_1 decreases;
4. both increase with A_1 proportionally more than K_1.

The same combinations are equally possible for the slow component of oxygen debt. Thus, improvement of total oxygen debt depends on many possible combinations of its parameters.

From the limited literature related to the problem, the following is known: 1. In studies when mild exercise test was given before and after a period of training, only the fast component of the oxygen debt, K_1, increased and

A_1 remained unchanged. Total oxygen debt was reduced (10, 43, 45). 2. In studies where subjects were given increasing work tasks the higher work load (still below maximum) increased the total oxygen debt more than the lower work load. Both slow and fast oxygen debt increased (improved). An improved fast component was accommodated by a higher A_1 and an unchanged K_1 and a higher A_2 and slower K_2 accommodated the improved slow component (10, 46). The literature on the effect of training, on oxygen debt and its parameters in the final stages of preparation of athletes for competition is non-existent. This study is believed to be the first experiment of such nature. Therefore it was impossible to predict the possible changes of parameters of an improved total oxygen debt.

Statistical significance in method x testing interactions was analyzed by using Harter's multiple comparison procedure for interactions (37). The significant range at the five percent level for tests of ordered means two and three steps apart, with ten degrees of freedom for the standard error of the mean, were 3.15 and 3.88, respectively. Hence the range of all three interaction elements was judged significant at five percent level if it exceeded $s_{\bar{d}} \times 3.88$, that of two adjacent ordered interaction elements was judged significant at that level if it exceeded $s_{\bar{d}} \times 3.15$. The value of $s_{\bar{d}}$ was obtained by $(2\ s^2/3)^{1/2}$, where s^2 represented error mean square.

CHAPTER IV

RESULTS AND DISCUSSION

PART I: RESULTS

Rowing performance scores and total oxygen consumption values are shown in Table 3.

Table 3

Rowing Performance (R.P.) Score in Ergs/6 min and Total Oxygen (T.O.) Consumption Score in L/15 min.

Method	Subject	Testing 1		Testing 2		Testing 3	
		R.P.	T.O.	R.P.	T.O.	R.P.	T.O.
M A	S 1	1683	11.008	1714	13.822	1911	16.481
M A	S 2	1698	10.494	1851	10.914	1934	13.172
M A	S 3	1647	11.011	1731	11.835	1872	12.512
Mean		1676	10.838	1765	12.190	1905	14.055
M B	S 4	1648	11.237	1735	12.092	1822	13.479
M B	S 5	1682	9.290	1725	9.502	1817	10.963
M B	S 6	1718	10.957	1822	11.215	1899	11.924
M B	S 7	1584	11.252	1775	11.179	1887	12.270
Mean		1658	10.684	1764	10.996	1856	12.159

All Ss scored higher on the rowing performance over the

three tests and showed a statistically significant F (112.07, Table 4) over trials.

Table 4

Analysis of Variance for Rowing Performance Score

Source of Variation	d.f.	Mean Square	F	Probability
Method	1	2681.28	<1	
$S_w M$	5	4307.66		
Testing	2	157339.59	112.07	$<.01$
M x T	2	2062.45	1.469	$>.01$
$S_w M$ x T	10	1403.8		

The single departure from a progressive increase of oxygen debt values for all Ss over trials was S 7 at test 2. The value of total oxygen debt for S 7 decreased in testing 2 (11.170) over the value of oxygen debt attained in testing 1 (11.252), but increased in testing 3 (12.270).

Table 5

Analysis of Variance for Total Oxygen Debt

Source of Variation	d.f.	Mean Square	F	Probability
Method	1	6.009	1.687	$>.05$
S_wM	5	4.763		
Testing	2	19.401	37.058	$<.01$
M x T	2	2.634	5.032	$<.05$
S_wM x T	10	.523		

Subgroup means for method A and B for total oxygen debt and rowing performance were quite closely matched at test 1, but were different at test 3, group A having the largest improvement in both parameters. However, there was no significant difference between the two methods used as shown by analysis of variance in Tables 4 and 5.

There was a significant method x testing interaction for total oxygen debt values at .05 level of significance. Further investigation of the nature of this interaction was not possible to determine since analysis of interactions did not yield statistical significance for the ranges of the two adjacent and of all three ordered interaction elements.

Predicted and observed oxygen debt curves for Ss 2, 5, and 7 are plotted in Figure 4 on page 62. The graphs demonstrate that the mathematical curve fitting was sufficiently accurate to permit analysis by the method described in Chapter III. Subgroup oxygen debt curves for all three testings are shown in Figures 5 and 6 on pages 63 and 64. The curves approximate each other very closely in form, but method A curves in testings 2 and 3 are above the curves of method B. In testing 1, method A curve started off higher, but took a lower position in the latter portion.

The mathematical curve $A = A_1e^{-K_1t} + A_2e^{-K_2t}$ was fitted to the experimental oxygen recovery data for each S for each of the three testings. The calculated values for A_1, K_1, A_2, and K_2 for all Ss are given in Table 6 on page 65. The mean values for the subgroups in Table 4 are the averages of the individual values. Between testing 1 and testing 3 there is a general change in numerical values of A's amd K's: the A's and the K_1's increased and the K_2's decreased, but there were exceptions. These exceptions were:

For method A: A_1 in testing 2;

K_1 in testing 3 increased over K_1 in testing 1, but not over K_1 in testing 2.

For method B: A_2 in testings 2 and 3.

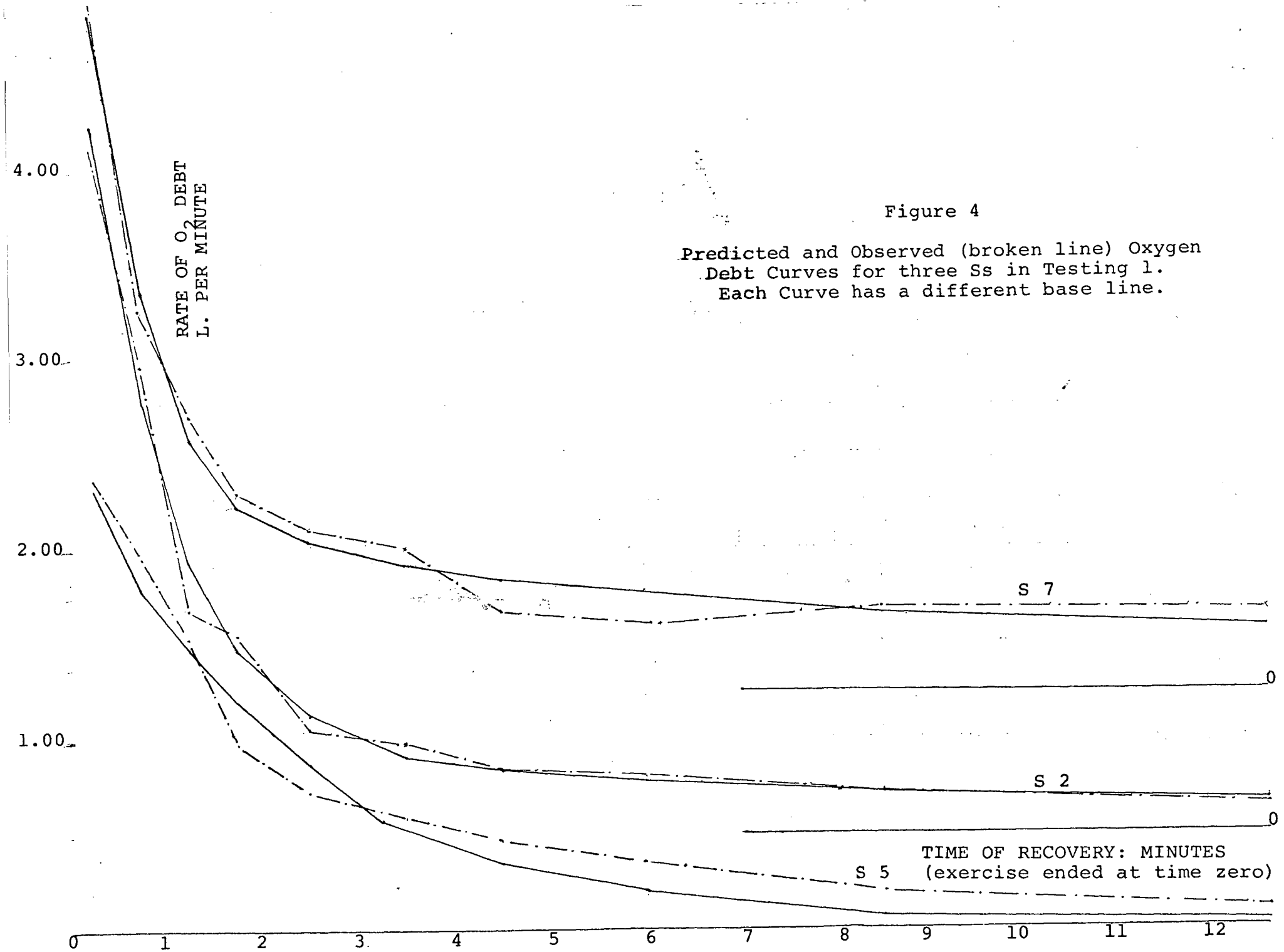

Figure 4

Predicted and Observed (broken line) Oxygen Debt Curves for three Ss in Testing 1. Each Curve has a different base line.

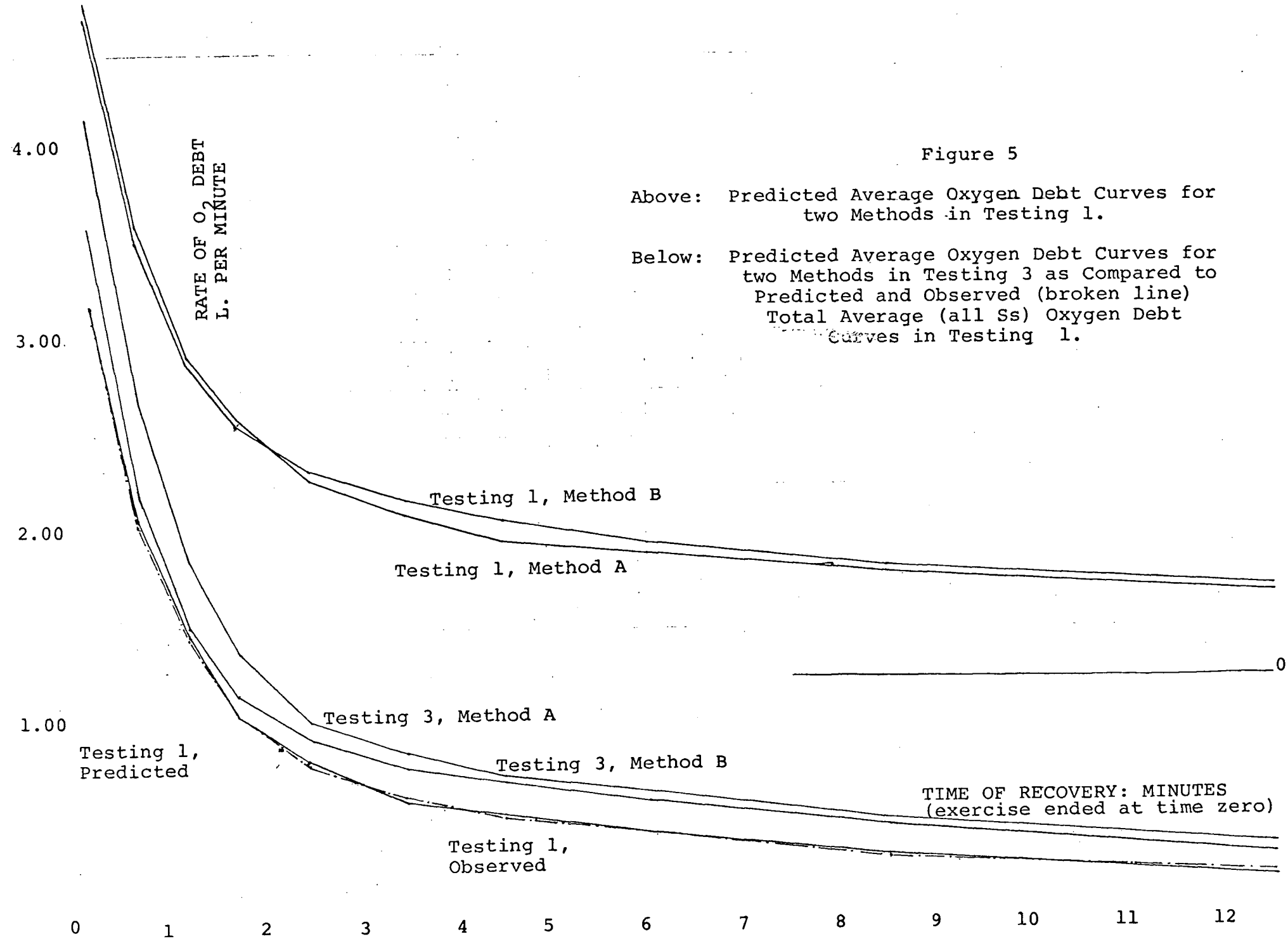

Figure 5

Above: Predicted Average Oxygen Debt Curves for two Methods in Testing 1.

Below: Predicted Average Oxygen Debt Curves for two Methods in Testing 3 as Compared to Predicted and Observed (broken line) Total Average (all Ss) Oxygen Debt Curves in Testing 1.

Figure 6

Average Oxygen Debt Curves for Method A and Method B in Testing 2.

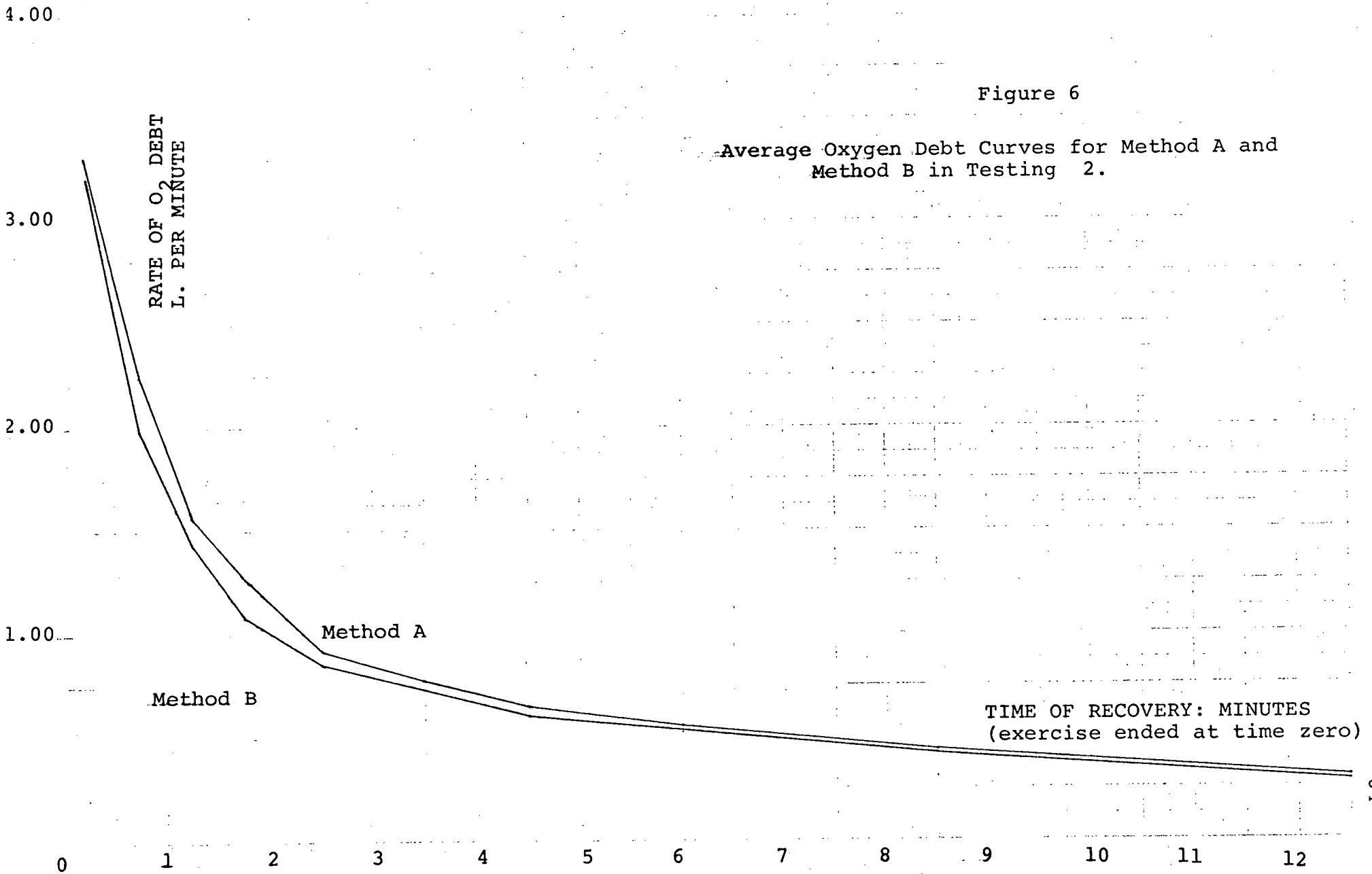

Table 6

Predicted Oxygen Debt Parameters A_1 and A_2 in L/min, and K_1 and K_2 in min^{-1}.

Meth.	S	Testing 1				Testing 2				Testing 3			
		A_1	K_1	A_2	K_2	A_1	K_1	A_2	K_2	A_1	K_1	A_2	K_2
A	1	3.972	1.594	.9384	.1163	3.175	2.846	2.0917	.1840	4.134	.8434	.9483	.0542
A	2	4.382	1.172	.4891	.0922	3.665	1.014	.5070	.0592	5.078	1.3770	.8246	.0798
A	3	3.129	.810	.5276	.6396	3.081	.978	.8131	.0749	4.080	1.3840	.9387	.0838
Mean		3.827	1.192	.6517	.2826	3.307	1.613	1.1373	.1060	4.430	1.2014	.9039	.0726
B	4	3.837	1.689	1.1267	.1470	4.347	2.030	1.2734	.1376	4.318	1.4910	1.1142	.0935
B	5	2.378	.650	.4115	.0765	2.557	.605	.2443	.0011	2.696	.9310	.0795	.0929
B	6	3.274	1.387	.8993	.0907	3.436	1.505	.8941	.0708	3.942	1.7070	1.0020	.0783
B	7	4.115	1.601	.8591	.0836	3.757	1.467	.8103	.0673	4.768	1.9590	1.0590	.0916
Mean		3.401	1.332	.8241	.0994	3.524	1.402	.8055	.0692	3.941	1.5220	.8137	.0891

The analyses of variance yielded no significant F's for methods' effect for all four parameters. For parameter A_1 (Table 7, A) there was a highly significant F (34.37) for testing effect, and there was a significant testing x method interaction for A_1 at .01 level of significance. In order to investigate further the nature of this significant finding Harter's procedure was used. The standard error of each interaction element ($s_{\bar{d}}$) was found to be .1918. The critical value for the range of all three interaction elements was .744 (.1918 x 3.88) and for the range of two adjacent ordered interaction elements .604 (.1918 x 3.15). The range between the first (difference between the subgroup means for A_1 from testing 2) and the second (difference between the subgroup means for A_1 from testing 1) value of ordered differences between the subgroup means for A_1 from all three testings was .642. This range value was significant since it exceeded the critical value .604 and was the only significant value. Thus the only significant interaction was found to be between testing 1 and testing 2.

Table 7

A. Analysis of Variance for A_1

Source of Variation	d.f.	Mean Square	F	Probability
Method	1	.287	<1	
$S_W M$	5	1.364		
Testing	2	2.162	34.270	$<.01$
M x T	2	.533	8.458	$<.01$
$S_W M$ x T	10	.063		

B. Analysis of Variance for K_1

Source of Variation	d.f.	Mean Square	F	Probability
Method	1	.035	<1	
$S_W M$	5	.561		
Testing	2	.208	<1	
M x T	2	.250	1.090	
$S_W M$ x T	10	.229		

C. Analysis of Variance for A_2

Source of Variation	d.f.	Mean Square	F	Probability
Method	1	.0028	<1	
$S_W M$	5	.3199		
Testing	2	.2268	2.7770	$>.05$
M x T	2	.2500	3.0604	$>.05$
$S_W M$ x T	10	.0816		

D. Analysis of Variance for K_2

Source of Variation	d.f.	Mean Square	F	Probability
Method	1	.0175	1.0778	$>.05$
$S_W M$	5	.0163		
Testing	2	.0398	2.3665	$>.05$
M x T	2	.0267	1.5893	$>.05$
$S_W M$ x T	10	.0168		

The results for subjective feelings of fatigue, Table 8, show slightly higher values for crew A, both immediately after the training sessions and 24 hours later.

Table 8

Median Fatigue Scores

Week	Immediately after training Crew A	Crew B	24 hours after training Crew A	Crew B
1-6	4	3	1	0
6-8	6	4	3	1

Summary. The theoretical exponential function was fitted to the oxygen data in recovery for all Ss. Parameters of the oxygen debt curve were derived and treated statistically with analysis of variance for repeated measures two by three factorial experiment. The only significant F was found for testing effect and method x testing interaction effect for parameter A_1. The Harter procedure was used to further investigate the nature of this significant interaction. Rowing performance and total oxygen debt values for all Ss were treated in the same way as the parameters. There was significant difference between the testings, but not between the methods. Significant method x testing interaction was found for total oxygen debt values, but the exact nature of this interaction was not possible to determine.

PART II: DISCUSSION

Nature of Rowing Test

In experimental studies of the effects of short-term special training on athletes who are already very fit, it is extremely difficult to elicit improved physical performance from testing to testing. Psychological factors have considerable influence not only on individual scores during testing, but also on each training session prior to the experimental testing. If an improvement from an already high athletic performance is to be attained at the end of the experimental training period, then a particular effort has to be made to secure high and consistent motivation. Individual willingness to exert maximally in training and testing may change and this may produce unreliable test data. It is likely that the most willing and co-operative oarsman could not, under the conditions of the study, develop the maximal power output reached during important races. Every element can be supplied artificially in experiments like these, except one, i.e., the intense combative emotion which is necessary to drive each athlete close to his utmost physical abilities. This problem of eliciting consistently the "all-out" performance is an important one in studies such as this and must always force the investigator to experience caution

in the interpretation of his results.

The small groups used to test the specific hypothesis pose a rigour on the data which is critical. Atypical performance by one or two subjects can influence the results powerfully. In this study the general trend was for rowing performance in ergs to increase concomitantly with the total oxygen consumption in recovery. Subject 1 from group A, however, increased his total oxygen consumption in recovery atypically (larger than typical) whereas his rowing performance remained typical. Subject 7 (group B) increased his rowing performance relatively more than the remaining subjects, but his total oxygen consumption in recovery decreased in test 2 compared with test 1.

If rowing exceeds other athletic activities in the amount of power output possible, the performance of the subjects in this study should approximate the maximum that the human engine can attain. The conditions of this study, therefore, were very different from those in which subjects performed qualitatively different types of exercises under submaximal conditions.

The test exercise used in the present study was rowing ergometer work for six minutes at the maximum possible rate. It is probable that rowing is a form of exercise in which the total energy expenditure attainable for periods of six minutes is greater than under any other conditions. No other exertion comes so near to involving the entire

muscle mass of the body in maximal effort.

Running is mainly leg work; the arms are swung, but the call on the muscles of the upper limbs is comparatively small. The trunk muscles act mainly as fixators. Although bicycling and bench stepping exercise permit a large power output the mass of active muscle involved is much smaller than in rowing.

The rowing stroke begins in a position of extreme flexion of trunk and legs and uses a powerful drive of the extensor muscles which are the stronger muscles of the body. The movement proceeds rapidly to full extension, pulling throughout against the high resistance of the oar, and ends with a powerful flexion of the arms. From this position, the recovery involves a rapid bending of the wrists, lowering the hands and shooting them forward, and a bending of ankles, knees, hips, waist and shoulders; this is accomplished by contraction of practically all the flexor muscles of these joints. Thus during the pull the greatest possible work is obtained from the extensors of the trunk and legs and from the flexors of the arms, while during the recovery the flexors of trunk and legs and the extensors of the arms, although less heavily loaded, are made to pass through a full range of flexion-extension. This process is repeated 30 or more times a minute.

The majority of studies (10, 14, 43, 45, 47, 65, 66) on metabolic recovery from exercise (running, bicycling or

bench stepping) have been related to submaximal exercise, the recovery from which may take several minutes only. In some studies (46, 47, 66), a more vigorous exercise was required. In these there appeared a slow component of post-exercise intake, but this approached the base line fairly quickly.

In 25 minutes of recovery following a six-minute bicycling exercise at 680 kgm/min De Moor (14) obtained a mean value of total oxygen debt for 22 men of 2.528 L whereas in this study the mean value of oxygen debt collected over 15 minutes was 14.005 L (method A) and 12.159 L (method B) in the last testing. In an experiment by Hill (47) the oxygen debt collected for one and one half hours after the end of a ten-minute exhausting run was 12.5 L for a fairly trained subject. In contrast, 16.4 L was the highest individual value (S 7) of oxygen debt and 9.29 L was the lowest (S 5) one in this study (15 minute collection only).

Oxygen Intake in Recovery (Debt) Curves

In order to show the nature of the oxygen consumption curves in recovery, the individual curves for three Ss have been drawn in one diagram (Figure 4); each is plotted from its own special base line which represents the final resting oxygen intake. The three curves are remarkably alike. In every case, after the vigorous rowing exercise lasting six minutes, the recovery oxygen intake falls from its high

initial value very rapidly in the first two minutes of the recovery phase. There is an obvious and large residual debt which declines slowly over the entire recovery period. It asymptomatically approaches the base line, but is still well above it after 15 minutes of recovery. These observations are very much in agreement with all the studies dealing with oxygen consumption in recovery (14, 43, 44, 45, 47). In this, there are clearly two factors at work - one which accounts for the initial rapid fall in the oxygen intake on the cessation of exercise, and another which is related to the prolonged residual recovery debt which in this experiment does not reach the base line until after 15 minutes. Each process is exponential in character - one is rapid; one, however, is slow.

As reported in the literature, moderate exercise is followed, to a preponderant degree, by recovery of the rapid type (10, 45). After quite gentle exercise, the recovery process is presumably even quicker than the most rapidly falling curve shown in the studies by Berg and Henry (10, 43). In this present study, it is clear that the second stage of the recovery process requires a long recovery period for its completion. This phenomenon has been observed and discussed by Margaria (66), Hill et al. (47), and others (7). It may take several hours for the

metabolism to reach resting level following a vigorous exercise such as rowing.

The work of Margaria, Edwards and Dill (66) and the earlier investigation of Hill et al. (47) has led to the fractionation of the oxygen debt pay-off curve into two components that may be described as the sum of two theoretical exponential terms, $A_1e^{-K_1t}$, and $A_2e^{-K_2t}$.

The close agreement of the theoretical curve with the experimental results shown in Figure 4 is fairly convincing, since the formula for oxygen consumption has only four parameters and there are only ten experimental points in the 15-minute recovery period chosen in this study. The fit is not as good as reported by Henry and his colleagues (43, 45) after mild exercise where only the fast component of the oxygen debt is observed. In Henry's work when a heavier work load (still submaximal) was introduced, which demanded an appearance of the slow component, a bigger scatter of experimental points was noticed (45), particularly at the bend of the curve. Berg (10) also reported similar considerable fluctuations from the theoretical curves. The deviation of observed data from theoretical data varies from individual to individual and is presumably caused by uneven ventilation and the changing of intrinsic factors in the individual (10). In Figure 4 the greatest fluctuation of observed data is exhibited by

S 7 and S 5, and the least variation by S 2. It is possible that a better fit could be obtained by using a more complex exponential function of the same form.

The use of mean scores for test 1 (all seven Ss) generates a much better fit of the theoretical curve to the observed data; the observed mean data present a smooth line as opposed to the irregular lines of the observed values for single individuals (Figure 5, page 63).

Rowing Performance, Total Oxygen Debt, and the Parameters of the Oxygen Debt Curves: A_1, A_2, K_1, K_2

The ability to use objective mathematical relationships to observe the patterns of oxygen consumption in recovery allowed Hill et al. (47) and Margaria et al. (66) to fractionate the oxygen debt phenomena into components. Since there are definitely two different mechanisms involved in recovery, fractionation of recovery oxygen into its alactacid or fast and lactacid or slow component allows careful studying of their responses to exercise and training. Each is described by two parameters A and K; A being the amount of oxygen used at the very beginning of exercise, and K representing its time or velocity constant. If $A_1 + A_2$ represent the relative amounts of oxygen intake that are removing oxidizable substrate (42) created during exercise by alactacid and lactacid mechanisms at minute zero of recovery, they must also represent the corresponding functions at the end of the exercise, whatever they might be.

The results for all the rowers as a single group show improvement in total oxygen consumption in recovery, in rowing performance and in the alactacid fraction A_1 of the oxygen intake at the termination of the exercise over the eight-week interval training program. The alactic velocity constant K_1 shows essentially no change. The lactic fraction A_2 and lactic velocity constant K_2 also show no statistically significant change. Although their respective F values (2.77 for A_2 and 2.36 for K_2) are not small, the average values of A_2 for method A and method B increased from the initial average values of .65 and 1.09, to .90 and 1.32 L/min. K_2 for both methods decreased from its average values of 1.28 and .13 to .07 min^{-1} for method A and .11 min^{-1} for method B.

The nature and direction of changes of the oxygen debt parameters in this study over the eight-week interval training programs (group A and B combined) are in agreement with previous research by Henry and De Moor (45) and Berg (10), although these men had investigated very different problem; they were interested in the problem of stability and the progressive change in the A's and K's due to a progressive increase in work loads. The different work loads caused considerable differences in the amounts and proportions of the fast and slow components of oxygen debt. As the work load increased, the alactic velocity constant K_1 showed essentially no change, but the value of

lactic velocity constant K_2 became progressively smaller. The alactic fraction A_1 of the steady state oxygen intake changed considerably with the work load. The lactic fraction A_2 also increased, but less rapidly. An increased load elicited an increase in oxygen debt which was accommodated by a change in A_1 and constant K_1 to account for a larger alactacid fraction and an increase in A_2 and K_2 to account for an increased lactacid fraction of the total oxygen debt. However, the main change in the slow component was due to alteration of K_2.

Total oxygen debt in this study increased significantly for the combined groups after eight weeks of training ($F = 37.05$). The increase in the alactacid fraction of the total debt was accommodated with significantly increased A_1 ($F = 34.270$) and the apparent increased lactacid fraction was accommodated by a simultaneous increase in both parameters responsible for the slow component of oxygen debt, i.e. A_2 and K_2. The apparent changes in these two parameters were not statistically significant (respective F values were 2.77 and 2.36), but were in the directions where the literature suggest they should go.

Henry and Berg (43) have shown that K_1 decreased due to training and A_1 remained unchanged under testing conditions using moderate exercise and the same rate of work for each test. The authors stated that the total metabolic cost rose more than the increased physical

performance. It is most likely that maximal oxygen intake remains constant in highly trained athletes over the late periods of the season, despite increasing work loads. If this is so, increased all-out performance under standardized condition is possible only by means of attaining a higher oxygen debt. This debt should increase proportionally more than the work performance because it is an inefficient method of providing for the metabolic cost of exercise. The results in the present study agree with this proposition. The rowing performance scores for method A increased by 13 percent over the eight-week period, but the total oxygen debt values increased by 23 percent over the same time interval. All Ss improved their oxygen consumption in recovery over the eight-week interval. S 1 showed the biggest gain of 4.4 L and S 7 showed the smallest gain of 1.4 L over this period of time.

Where physical performance is improved due to training and there is no change in efficiency there will be a concomitant increase in oxygen consumption. The more vigorous the exercise the greater becomes the importance of the oxygen debt part of this oxygen cost. The oxidizable substance that is created during the exercise will accumulate, minute by minute, to the extent that the oxygen requirement exceeds $A_1 + A_2$. Thus, any positive effect that training might have on the physical performance and in turn on total oxygen debt will be confounded with the positive effects that training might have on the factors of the two

oxygen debt components (alactacid and lactacid).

The general hypothesis of the study has been supported by the results since the subjects as a whole significantly improved rowing performance and total oxygen debt in the eight-week period of interval training.

Discussion on Changes in A_1+A_2 Due to Training in Exhausting Exercise

In Henry's study (46) rate of oxygen consumption at zero time in recovery (A_1 + A_2) equals the steady state oxygen consumption at termination of exercise. Higher intensity of work requires a higher steady state oxygen consumption thus an increased A_1 + A_2 value at higher work load is easily explained. In exercise where subjects are working at highest possible work level with an oxygen consumption at its physiological maximum level as was the case in this experiment, it becomes extremely difficult to explain a significant increase in A_1 and a mild increase of A_2. A_1 + A_2 have to equal oxygen consumption at termination of work whether it be submaximal or maximal. Obviously it cannot go beyond the maximal aerobic power (maximal oxygen intake). Jackson (55) as well as others (7) have shown that maximal oxygen consumption in trained athletes does not change due to additional training. Thus, a higher maximal oxygen consumption curve is highly unlikely to accommodate a significantly improved A_1.

The only possible explanation for higher $A_1 + A_2$ value in last testing is yielded by the "last minute oxygen consumption phenomenon" in exhausting exercise. It is known from previous research (55, 7) that the oxygen consumption in the last minute of exhausting exercise is falling from its preceeding maximal attained values although a high work load could still be maintained by the athlete for a limited period of time. This lower oxygen consumption at the termination of exercise causes a lower $A_1 + A_2$ at zero recovery time.

It seems a possibility that in peak training periods the "drop-off" in oxygen intake in the last stages of exhausting exercise diminishes and the oxygen intake at the termination of the exercise may be identical with the maximal aerobic power and may account for the changes in total group values for $A_1 + A_2$ obtained in this study. The occurrence of this peaking phenomenon is supported by an additional experiment of the writer with the same Ss during the early summer of 1972. All Ss were tested every four weeks for four times on the bicycle ergometer; they rode the bicycle until exhaustion. The initial work load of 1500 kgm/min was progressively increased every two minutes by 500 kgm/min and oxygen consumption was measured continuously during the exercise. Only in the last test, where all rowers reached the very maximum of their

potentials (five days before Canadian Olympic Trials) did their oxygen consumption in the last minute remain at maximum. This was in contrast to the other tests when the majority of oxygen consumption values dropped in the last minute. The physical performances improved as well at test 4, but the maximal oxygen consumption did not improve significantly.

The ability to use objective mathematical relationships to quantify and partition oxygen intake in recovery makes it possible to arrive at a better understanding of the dynamics of the oxygen debt and its response to exercise and athletic training.

Interval Training Methods A and B

The study has demonstrated that carefully collected physiological data from a controlled all-out exercise bout will conform very precisely to a predicted theoretical curve. Just as importantly, the study extends the earlier work of Henry (42, 43, 46) and his colleagues, showing that oxygen uptake following heavy work falls under the same mechanisms of physiological control as oxygen uptake during work of a light to moderate intensity. When the average oxygen debt curves (test 1) are plotted for groups A and B (Figure 5, Above), it is observed that method A curve starts off higher and is above the method B curve for the first two minutes of the recovery. After that point it runs below it until the end of the recovery phase.

After four weeks of training, the average oxygen debt curve for method A is at no point below the average curve for method B (Figure 6). After eight weeks of training the discrepancy between the two curves becomes even greater in favor of the average oxygen debt curve for method A. These graphs demonstrate an apparent greater improvement of group A over group B in total oxygen debt after eight weeks of interval training.

The results of the study clearly show that there are no statistically significant differences between the two methods in any of the measured parameters. All F values are quite low. The highest F ratio is for total oxygen debt (1.68) and for K_2 (1.07); all other values are well below 1. Thus, all specific hypotheses but two were rejected.

The data in Table 8 show that rowers following method A reported slightly higher values for subjective feelings of tiredness immediately after rowing and on the following day. All the rowers were quite familiar with use of fatigue scales since similar scales were used after almost all training sessions during the previous two summers. For this reason the rowers should have a reliable intrinsic subjective evaluation of their tiredness after the training sessions.

The results shown in Table 8 were in accord with stopwatch record of rowing times during interval training

sessions. Crew B had slightly faster average times in almost all interval sessions. The noticeable difference, however, was shown in the last two weeks of the experimental period when the interval sessions became longer and more frequent. Crew A seemed to accumulate tiredness from interval work session to interval work session and a few times they had to be sent off the water having done less repetitions than required by the program.

In contrast to results on the water during the training sessions, crew A showed apparently higher work performance scores on the rowing ergometer after eight weeks of training.

Group means for rowing performance were quite closely matched at test 1 (1676 and 1658 ergs), but were different at test 3 (1905 and 1856 ergs) in favor of method A. However, analysis of variance yielded a non-significant F value.

The F value for the difference between the methods in total oxygen consumption yielded a non-significant value. However, by inspection of Figure 5 and Figure 6 it is observed that method A did elicit slightly greater total oxygen debt than method B. In test 1 the predicted average oxygen curve of method A was below the predicted average oxygen curve of method B after two minutes of the recovery (Figure 5, Above); this changed in the subsequent testings. In the last testing, the average method A curve is well

above the average oxygen curve of method B for its entire length (Figure 5, Below). The same phenomenon occurred in testing 2 (Figure 6). Group means for total oxygen consumption were quite closely matched at test 1 (10.83 and 10.68 L), but were different at test 3 (14.05 and 12.15 L) in favor of method A.

Two important factors might have had crucial bearings on the experimental results: 1. One S from crew A had to be replaced which caused problems of the adjustment of crew A to the new member. It took almost three weeks for crew A to regain its previously established boat moving ability. During that time, although the crew followed the program rigidly, the crew members were not able to achieve full exhaustion after every bout (all-out effort in each of the bouts was the chief requirement of the experiment). 2. Any experimentally demonstrable improvement in performance and recovery oxygen intake was made difficult because of the high state of physical condition achieved by the rowers prior to the experimental period. Under such conditions any differences between the two methods that might have been created should be difficult to show and would be expected to be small.

In this study the results showed no difference between the training method A and training method B. Specific hypotheses 1, 2, 3, and 4 were not supported. The results obtained, however, were in the direction

expected by the stated hypotheses. These findings support the experience of the investigator who coached both crews, i.e., that method A is worth persisting with in rowing training and also in further studies, particularly with more subjects to investigate its efficacy further. In their written responses to the training methods at the end of the experimental period all Ss stated that they were generally happy with the respective interval training methods used in this study.

The improved rowing performance and good feeling of the Ss at the end of the experimental period supported the views of the rowing and track experts (1, 17, 30, 64, 77, 80, 97) that interval training is necessary in the last stages of the preparation of athletes for competition. Training at racing pace is advisable with inclusion of workouts of high anaerobic fartlek rowing where maximal rating at maximal possible speed is attained by the crew.

CHAPTER V

SUMMARY AND CONCLUSION

The purpose of this study was to determine whether or not one training procedure used in the preparation of varsity rowers for competitive rowing is superior to another. Improvement in total work performance on the Leichart rowing ergometer, improvement in oxygen debt and subjective responses of the rowers to the methods were used as criteria in judging the superiority of one method over the other. Improvement in the slope and the rate of the fast phase and slow phase of the oxygen debt curve provided additional criteria. Eight varsity rowers were divided into two equally fast "four-oar" crews and assigned to two interval training programs in the late stages of preparation for competitive season. Subsequently one subject had to be replaced, therefore only seven subjects were experimentally treated.

All rowers were expected to improve their rowing performance as well as their total oxygen debt after an eight-week training program. The rowers following training program A were expected to show greater improvement in these two parameters than rowers following training program B. Additionally, greater improvement in the slope and rate of oxygen intake of fast and slow component of the oxygen debt

curve was expected from the rowers under program A. After each interval training session they would subjectively experience a higher state of fatigue. The three experimental testings measured total work performance completed in six minutes and total oxygen consumption obtained in 15 minutes of recovery. Subjective written responses to the training sessions were collected on daily basis.

A theoretical exponential function of the form $A = A_1e^{-K_1t} + A_2e^{-K_2t}$ was fitted successfully to the observed oxygen debt pay-off values of each subject with the purpose of obtaining the predicted values for collection intervals and the parameters that describe slow and fast components of oxygen debt curve, A_1, K_1, A_2, and K_2. Analysis of variance was used in order to study the effect of training and the effect of the two training methods on the experimental subjects.

The results showed that there was a significant statistical improvement over trials in rowing performance, total oxygen debt and A_1 parameter of oxygen debt curve for the rowers as a total group. There was no significant difference between the two training programs in any of the test parameters. The results obtained, however, were in the direction expected by the stated hypotheses.

The conclusions were as follows:

1. There was no significant difference between the two methods used.

2. The eight-week rowing program, with concentration on interval training, significantly improved rowing performance and total oxygen debt of the subjects.

3a. The theoretical function of the form $A = A_1e^{-K_1t} + A_2e^{-K_2t}$ successfully fitted the experimental oxygen debt data.

3b. Oxygen debt curves after an exhaustive rowing exercise were similar in shape to curves obtained in moderate exercise by other experimenters.

3c. The changes shown by the oxygen debt curves due to training are similar to changes on oxygen debt curves generated by increasing work loads in submaximal conditions.

4. The increase in $A_1 + A_2$ was presumably due to ability of subjects to maintain a higher oxygen consumption in terminal stage of work.

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APPENDIX A

INSTRUCTIONS FOR TESTING PROCEDURE

1. Rest for 15 minutes in supine position.
   Change your clothes and weigh in.

2. Warm-up: 10 minutes jogging - stretching
   5 minutes rowing on ergometer
   1 minute all-out row (recording)
   3-5 minutes rest

3. Testing
   A. all-out row for 6 minutes
   B. collection of expired gases for 15 minutes.

APPENDIX B

FATIGUE SCALE QUESTIONNAIRE

Date: _____

Name: _____

How many hours did you sleep? _____

What was your pulse rate: in the morning? _____
before bed? _____

What was your weight: before workout? _____
after workout? _____

State degree of general tiredness still felt from your last workout:

0. not at all _____
1. very, very slightly _____
2.
3. slightly _____
4. fairly light _____
5.

Other comments on your feelings on health in general before workout, e.g., sleepy, sore throat, sore muscles, etc. _____
_____

Did you enjoy the workout? (if not why?) _____

State the feeling of tiredness:

1. somewhat tired _____
2.
3. tired _____
4.
5. very tired _____
6.
7. completely exhausted _____