2

Intermediate Rowing Physiology

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1.0 INTRODUCTION

The FISA CDP booklet titled BASIC ROWING PHYSIOLOGY provided information about the energy requirements of a rowing race. The information included a description of aerobic and anaerobic metabolism with an emphasis on the major systems and components of aerobic metabolism.

As this booklet will expand and not extensively review that material, the reader is encouraged to review the FISA CDP Level I booklet.

This booklet will present more information about metabolism, the effects of training on metabolism and some simple tests to measure those effects.

2.0 ENERGY FOR ROWING

The human body acts as an engine to propel the rowing boat across the water. As explained in level I, the boat is pried forward across the surface of the water by an athlete seated in the boat and moving forward and backward on a sliding seat while pulling on an oar placed intermittently in the water.

The body, acting as an engine, produces power by the application of force which provides the boat with a forward velocity (see Figure 1).

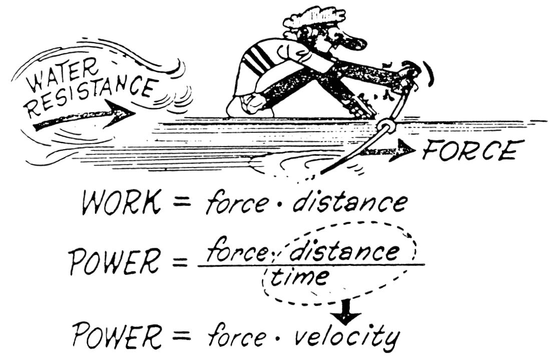


Figure 1. Production of Power

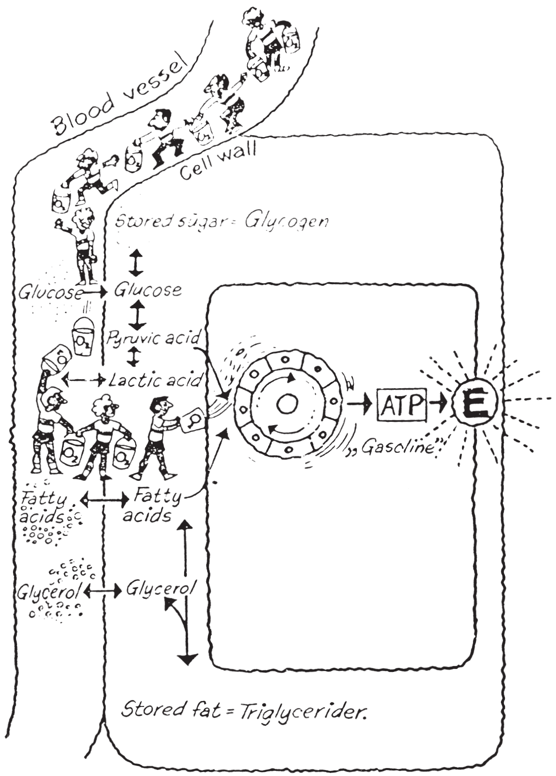


Figure 2. Production of Energy

Force is applied by the contraction of muscles which requires energy. The source of the energy for muscle contraction is the breakdown of chemical bonds in the muscle cells. These chemical bonds are provided by chemical substances stored in the muscles:

1. ATP (adenosine triphosphate),
2. CP (creatine phosphate),
3. glucose (stored as glycogen), and
4. fats.

ATP is the only substance that can directly supply energy for muscle contraction. As the muscle cells only contain enough ATP for

a contraction of a few seconds, it is necessary to replace the ATP. The other substances are indirect sources of energy since they supply energy for the resynthesis or replacement of ATP.

The relationship between ATP and the principal sources of energy, glucose and fats, to replace ATP is illustrated in figure 2.

3.0 THE REPLACEMENT OF ATP

The replacement or resynthesis of ATP is generally considered to involve three processes:

1. ATP-CP Reaction.
2. Anaerobic Glycolysis.
3. Aerobic Metabolism.

3.1 The ATP/CP Reaction

The stored CP in the muscle cell is a high energy substance similar to ATP. It can provide the energy to resynthesize ATP rapidly but the amount stored is only sufficient for less than twenty seconds. Since this process is conducted in the absence of oxygen and does not produce lactic acid, it may be referred to as alactic anaerobic metabolism.

Although this process will provide energy for the start phase of the race, its contribution is a small percentage of the total energy requirements of the body during the 2000 meter rowing race.

3.2 Anaerobic Glycolysis

The production of energy in the absence of oxygen which does produce lactic acid may be referred to as lactic anaerobic metabolism. This was presented in BASIC ROWING PHYSIOLOGY as an important source of energy during the start and finish phases of the rowing race.

This process results in the production of energy for the resynthesis of ATP through the breakdown of carbohydrates (primarily glycogen stored in the muscle cell, therefore this is termed anaerobic glycolysis). It can provide the energy almost as rapidly as that supplied by the ATP/CP reaction.

A great amount of energy may be supplied by this process but the depletion of glycogen and the accumulation of lactic acid in the muscle cells results in the reduction of the muscle's ability to contract. The accumulation of lactic acid may also cause pain in the muscle of the athlete. Due to these effects, it is not possible to use this process for prolonged periods. Therefore, the process is utilized primarily during the start and finish phases of the race.

Although this system may provide energy for up to 2-3 minutes of intense activity (for the period of 30-90 seconds after the start and during the 60-90 seconds of the finish phase), it will only provide about 20-25% of the energy requirements of the rowing race.

3.3 Aerobic Metabolism

Aerobic metabolism provides about 75-80% of the energy requirements of the rowing race. It involves the combustion of a fuel in the muscle cell in the presence of oxygen. The source of the fuel is generally from either glycogen or fats stored in the muscle, or glucose and fats stored elsewhere in the body, and delivered by the circulatory system to the muscle cells (see figure 2).

As this process depends on many more reactions in the muscle cell, the energy is released more slowly and depends on a sufficient supply of oxygen being delivered to the mitochondria; the power plants of the muscle cell (see BASIC ROWING PHYSIOLOGY). Therefore, the respiratory and cardiovascular systems must be capable of delivering oxygen from the air we breathe to the muscle cell.

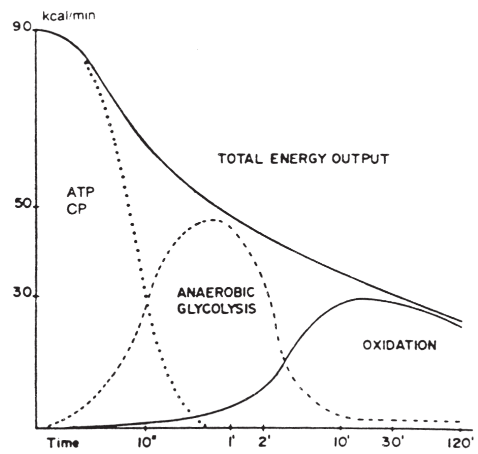


Figure 3. The Importance of Aerobic Metabolism

It takes about 60-90 seconds to activate these two systems to provide sufficient oxygen to aerobically meet the energy requirements of the muscle cell during a rowing race. The continual sufficient supply of oxygen during the middle or distance phase of the rowing race enables the body to replace the ATP almost exclusively from aerobic metabolism. Unlike anaerobic metabolism with its debilitating waste product, lactic acid, the by-products of aerobic metabolism, water and carbon dioxide, are either eliminated to the atmosphere or partially retained (water) to assist in body functions.

It should be noted that aerobic metabolism is actually two processes:

1. Lipid metabolism (the breakdown of fats), and
2. Aerobic glycolysis (the breakdown of glycogen).

Since lipid metabolism provides abundant energy, it is an important source of energy for training; but, due to the fact that the reactions are very slow, it is generally not useful during a 2,000 meter rowing race. For this distance, aerobic glycolysis and its complete breakdown of glycogen is utilized.

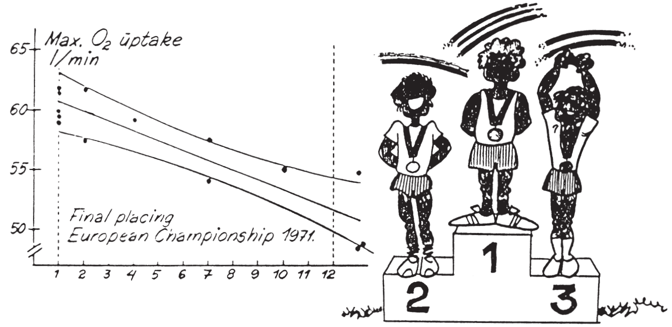
3.4 The Interaction of The ATP/PC Reaction, Anaerobic Glycolysis and Aerobic Metabolism

The replacement of ATP during a rowing race is dependent on the interaction of the three processes:

1. the ATP-PC Reaction (less than 5%)
2. anaerobic glycolysis (20-25%)
3. aerobic metabolism (75-80%)

These three processes do not operate in isolation or independently during exercise but occur simultaneously and are integrated to provide the necessary energy to satisfy the requirements of the rowing race. This is illustrated in figure 4.

Adapted from `Energy stores and substrates utilization in muscle during exercise' by Howald, H., et al in The Third International Symposium on Biochemistry of Exercise. F. Landry and W.A.R. Orban (eds.), Miami Symposia Specialists, 1978.



The relationship between maximal oxygen uptake of individual Scandinavian rowers and their final placing in the European championship 1971: the higher the maximal oxygen uptake, the better the performance.
The outer lines indicate 95 percent confidence limit.
(From Secher et al. 1976)

Figure 4. The Output of Energy

The exact determination of the relative contribution of the three processes is difficult to determine but most physiologists agree that the athlete's maximum oxygen uptake or VO2 max represents the maximal total aerobic metabolic rate.

This is an important measurement because of the relative importance of aerobic metabolism to rowing. This is demonstrated by the research findings illustrated in figure 3.

Although a generally accepted method to measure an athlete's anaerobic capacity is not available or is impractical to perform, measurements of lactate in blood after exhaustive exercise have been used frequently as a gauge of the athlete's ability to tolerate high concentrations (an ability that may improve with training). A measure of lactate concentration in the blood during exercise at below maximal level is also used to gauge the fitness level of the athlete.

Another measurement that may be used to gauge the fitness level of the athlete and is useful in providing training assistance is the determination of the anaerobic threshold.

Essentially, the energy requirements of the body exercising at a training load below this threshold will be met primarily by aerobic metabolism whereas exercising at a training load above this threshold places an increasing demand on the anaerobic glycolytic process. This is illustrated in figure 5.

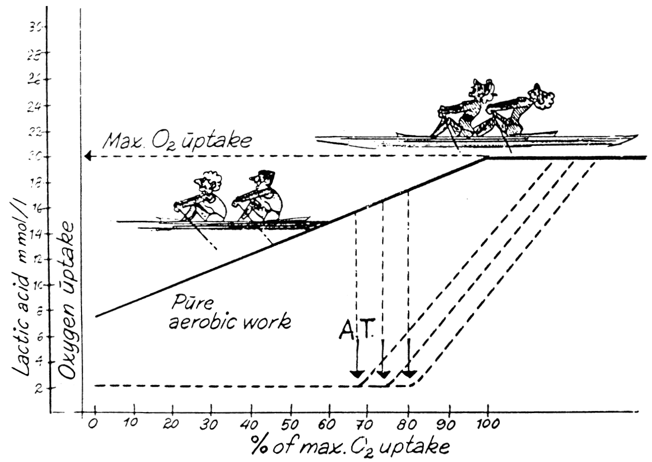
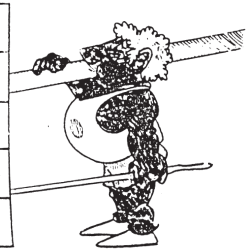


Figure 5. Anerobic Threshold

It is obvious that the purpose in training for rowing would be to enable the athlete to both increase the maximum oxygen uptake and to able to use a greater percentage of this level before obtaining the significant increases in lactate concentrations. In figures 5 and 6, the result of a successful training programme is illustrated.

Improvement in physiological factors from Dec. to May in a group of American oarsmen. (Heavyweight)
(From F. C. Hagerman)

	DEC.	FEB.	MAY
O_2-uptake l/min.	5,41	5,65	6,16
ml/kg/min.	59,6	62,0	68,4
A.T. (%)	72	75	83
VO_2 - A.T.	3,92	4,27	5,14
Watts	345	380	393



As a result of strength and endurance training.

Figure 6. Improvements in Physiological Factors

Some other methods to measure these processes and comments about the effects of training will be presented in the following sections.

4.0 MEASUREMENTS

The scientific measurement of the energy systems generally requires the use of expensive equipment and experienced researchers but, through the use of some simple techniques, useful information can be provided to assist the athlete and coach.

4.1 VO2 Max / Testing of Aerobic Metabolism

The most common method used in rowing to measure aerobic metabolism is the determination of maximum oxygen uptake or VO2 Max. The direct determination of this measurement does require the use of expensive equipment and the assistance of an experienced researcher.

Although the determination of this measurement is not necessary to produce world class rowers, it does provide information to:

1. Assess the suitability of an athlete for the sport.
2. Determine the effect of a training programme.
3. Measure the athlete's rate of improvement.

The use of measuring physiological factors in determining the effect and rate of improvement due to a training programme has been illustrated in figure 6. The determination of maximum oxygen in various categories for international athletes in rowing is illustrated in figures 7 to 10.

Although the direct method is better, an indirect measurement method may be used to predict VO2 max. The prediction is made from the results of submaximal exercise and is based on the assumption that a relationship exists between VO2 and the other more easily measured variables during submaximal work loads and those extrapolations to maximal work loads can be made to estimate or predict VO2 max. Two predictive tests are:

1. a step test: a test requiring a step up to and step down from a bench (33 cm and 40 cm high for women and men, respectively) at a rate of 30 steps per minute for five minutes; the pulse taken for one minute following the conclusion of the test is used to read from the Astrand nomogram to predict VO2 Max (see Appendix A).
2. a bicycle test: a test requiring a ride on a bicycle ergometer for a given submaximal work load that is sufficient to maintain a heart rate in excess of 120 beats per minute for a period of two minutes; the average pulse taken over the two minutes is used to read from the Astrand nomogram to predict VO2 max.

Although these tests do not use rowing specific testing equipment (such as a rowing ergometer), they do provide some information and may be particularly useful for club level programmes. These predictive tests are inexpensive, easy to administer and excellent for group testing but are subject to error, particularly for very low or very high VO2 max categories.

4.2 Testing of Anaerobic Metabolism

It should be remembered that the anaerobic energy system provides energy for short term intense exercise from the breakdown of glycogen and energy rich substances. It is possible to perform some simple tests to provide some information about the capacity of this metabolic system. The testing procedures could be:

1. alactic anaerobic capacity: a maximum effort for about 10 to 15 seconds.
2. lactic anaerobic capacity: a maximum effort for about 30 to 90 seconds.

The method used would be to either compute the amount of mechanical work that can be performed in the specified time or record the time required to perform a given amount of anaerobic work by the use of:

1. the lifting of barbells,
2. the performance of exercises/calisthenics, or
3. the rowing or bicycle ergometer.

The computation of the amount of mechanical work is generally the preferred method and is a simple procedure that may also be correlated with a more complicated procedure of the computation of lactic acid produced during the lactic anaerobic capacity test. This latter computation must be determined from a sample of blood taken from the athlete during or immediately after the test. The taking of blood is termed an invasive testing procedure because it involves the taking of a physical sample from the body of the athlete.

An example of a non-invasive testing procedure which does not require the taking of a physical sample would be the recording of the heartrate by either touching the body or using an electronic device attached to the body. This procedure may be used in the predictive measurement of VO2 max or in a determination of the anaerobic threshold.

Name :

ID-Nummer : 2
Grße (cm) : 193
Druck (mmHg) : 726
Geschlecht(M/F): M
FIO2 (%) : 20.81

Datum : 20-04-88
Alter : 26
Gewicht (kg) : 90
Temp (C) : 22.3
30 5.7

Time Min	Work Watt	HR	BF	RQ	EQ-CO2	VE l/min	Vo2 l/min	Vo2/mL kg*min	MET	VO2/kg /HR	VCo2 l/min	FCo2 %	EQ-O2
0:30	450	158	37	1.13	41	82.2	1.75	19.5	5.6	0.12	1.99	3.07	47
1:00	420	171	59	0.85	40	161.3	4.79	53.3	15.2	0.31	4.07	3.20	34
1:30	420	178	63	0.92	38	214.6	6.10	67.8	19.4	0.38	5.61	3.32	35
2:00	390	174	67	1.00	38	227.3	6.00	66.7	19.1	0.38	6.03	3.37	38
2:30	400	175	64	1.03	37	227.7	5.95	66.1	18.9	0.38	6.11	3.41	38
3:00	380	178	65	1.03	37	236.1	6.11	67.9	19.4	0.38	6.31	3.39	39
3:30	390	180	67	1.03	37	234.7	6.09	67.7	19.3	0.38	6.30	3.41	39
4:00	370	181	62	1.02	37	229.2	6.03	67.1	19.2	0.37	6.16	3.42	38
4:30	390	179	65	1.01	38	233.8	6.13	68.1	19.5	0.38	6.18	3.36	38
5:00	380	178	64	1.01	37	232.6	6.16	68.4	19.6	0.38	6.21	3.39	38
5:30	380	181	68	1.00	38	235.5	6.18	68.6	19.6	0.38	6.19	3.34	38
6:00	434	180	67	1.01	38	229.6	5.98	66.4	19.0	0.37	6.02	3.33	38
6:30												3.34	
7:00												3.32	
Max	450	181	68	1.13	41	236.1	6.18	68.6	19.6	0.38	6.31	3.42	47
Pred		193				199.5	3.37	45.7					
%Pre		92%				118	183	150					

Figure 7. Testing Results / Senior Men

Name :

ID-Nummer : 07
Grße (cm) : 181
Druck (mmHg) : 727
Geschlecht(M/F): M
FIO2 (%) : 20.81

Datum : 20-04-88
Alter : 21
Gewicht (kg) : 68
Temp (C) : 23.9
30 4.5

Time Min	Work Watt	HR	BF	RQ	EQ-CO2	VE l/min	Vo2 l/min	Vo2/mL kg*min	MET	VO2/kg /HR	VCo2 l/min	FCo2 %	EQ-O2
0:30	350	168	39	0.90	38	109.1	3.18	46.8	13.4	0.28	2.88	3.35	34
1:00	360	174	45	0.87	36	124.2	3.96	58.3	16.7	0.34	3.45	3.53	31
1:30	360	179	61	0.91	34	149.9	4.80	70.5	20.2	0.39	4.37	3.70	31
2:00	360	178	62	0.99	34	170.7	5.09	74.9	21.4	0.42	5.04	3.76	34
2:30	360	180	65	1.05	34	180.9	5.07	74.6	21.3	0.41	5.32	3.73	36
3:00	350	180	69	1.09	34	187.2	5.02	73.8	21.1	0.41	5.45	3.70	37
3:30	350	179	84	1.09	35	194.9	5.14	75.6	21.6	0.42	5.61	3.65	38
4:00	340	182	94	1.09	36	197.7	5.09	74.9	21.4	0.41	5.58	3.58	39
4:30	360	180	98	1.09	37	206.7	5.20	76.4	21.8	0.42	5.66	3.48	40
5:00	340	180	101	1.09	38	210.5	5.12	75.3	21.5	0.42	5.61	3.38	41
5:30	350	183	105	1.09	39	225.3	5.24	77.1	22.0	0.42	5.73	3.23	43
6:00	403	183	105	1.11	42	233.7	5.02	73.8	21.1	0.40	5.59	3.04	47
6:30												3.01	
Max	403	183	105	1.11	42	233.7	5.24	77.1	22.0	0.42	5.73	3.76	47
Pred		196				157.5	3.53	48.5					
%Pre		93%				148	148	159					

Figure 8. Testing Results / Lightweight Men

Name :
ID-Number : 06
Height (cm) : 185
B. P. (mmHg) : 723
Sex (M/F) : F
FIO2 (%) : 20.88

Date : 31-03-88
Age : 25
Weight (kg) : 78
Temp (C) : 21.4
30 4.1

Time Min	Work Watt	HR	BF	RQ	EQ-CO2	VE l/min	Vo2 l/min	Vo2/mL kg*min	MET	VO2/kg /HR	VCo2 l/min	FCo2 %	EQ-O2
0:30	300	154	63	1.04	43	75.3	1.70	21.8	6.2	0.14	1.76	2.98	44
1:00	308	171	63	0.81	42	113.6	3.36	43.1	12.3	0.25	2.73	3.07	34
1:30	308	165	63	0.88	38	132.9	3.94	50.5	14.4	0.31	3.47	3.33	34
2:00	308	168	62	0.96	37	140.2	3.94	50.6	14.4	0.30	3.78	3.44	36
2:30	291	172	63	0.99	37	147.3	4.06	52.1	14.9	0.30	4.00	3.47	36
3:00	300	168	61	1.00	36	143.5	3.96	50.8	14.5	0.30	3.98	3.54	36
3:30	291	172	59	1.00	36	144.3	4.07	52.2	14.9	0.30	4.07	3.60	36
4:00	291	177	65	1.01	36	153.4	4.17	53.5	15.3	0.30	4.23	3.52	37
4:30	291	177	65	1.02	36	151.5	4.13	52.9	15.1	0.30	4.20	3.54	37
5:00	300	179	66	1.03	36	159.0	4.26	54.6	15.6	0.31	4.37	3.51	37
5:30	291	179	67	1.02	37	159.2	4.21	53.9	15.4	0.30	4.30	3.45	38
6:00	291	178	67	1.03	37	158.4	4.17	53.4	15.3	0.30	4.29	3.46	38
6:30												3.42	
Max	308	179	67	1.04	43	159.2	4.26	54.6	15.6	0.31	4.37	3.60	44
Pred		194				143.5	2.25	38.8					
%Pre		92				111	189	141					

Figure 9. Testing Results / Senior Women

Name :
ID-Nummer : 05
Grße (cm) : 168
Druck (mmHg) : 725
Geschlecht(M/F): F
FIO2 (%) : 20.75

Datum : 13-05-88
Alter : 17
Gewicht (kg) : 60
Temp (C) : 23.9
30 3.2

Time Min	Work Watt	HR	BF	RQ	EQ-CO2	VE l/min	Vo2 l/min	Vo2/mL kg*min	MET	VO2/kg /HR	VCo2 l/min	FCo2 %	EQ-O2
0:30	258	171	40	1.05	38	97.2	2.45	40.8	11.7	0.24	2.57	3.36	40
1:00	267	174	57	1.00	38	128.9	3.36	56.0	16.0	0.32	3.36	3.32	38
1:30	258	177	55	1.09	36	139.1	3.54	59.0	16.9	0.33	3.86	3.53	39
2:00	241	179	50	1.14	35	143.6	3.59	59.9	17.1	0.33	4.11	3.64	40
2:30	241	180	54	1.17	36	145.1	3.49	58.2	16.6	0.32	4.08	3.58	42
3:00	233	181	52	1.15	36	151.2	3.71	61.8	17.7	0.34	4.27	3.59	41
3:30	225	180	52	1.12	36	144.1	3.62	60.4	17.3	0.34	4.05	3.58	40
4:00	225	182	65	1.11	38	164.7	3.91	65.1	18.6	0.36	4.35	3.36	42
4:30	241	183	65	1.16	39	158.6	3.52	58.7	16.8	0.32	4.09	3.28	45
5:00	293	185	47	1.11	35	130.5	3.35	55.8	16.0	0.30	3.71	3.62	39
5:30												3.76	
Max	293	185	65	1.17	39	164.7	3.91	65.1	18.6	0.36	4.35	3.76	45
Pred		199				112.0	2.36	41.7					
%Pre		93				147	166	156					

Figure 10. Testing Results / Lightweight Women

4.3 Testing of Anaerobic Threshold

Anaerobic threshold, as explained in section 3.4, is a metabolic response to an increasing work load when aerobic energy production is augmented by anaerobic energy production to satisfy the energy requirements of the exercising muscles. At this point, there is a corresponding onset of blood lactate accumulation. Although anaerobic threshold is a controversial scientific measurement, its determination may have some practical applications in the sport of rowing.

The anaerobic threshold is observed by determining the change in lactate accumulation in the blood or the change in ventilatory response during periods of increasing work loads. (The volume of air going into and out of the lungs is called ventilation.)

Although not as exact, another method is recording heartrate during increasing work loads. This non-invasive technique is based on the principle that, during continuous and progressive efforts, the linear correlation between heartrate and increasing work loads will change (or deflect) at the anaerobic threshold point. After this change, increasing work loads will be accompanied by smaller increases in heartrate.

The increasing work load may be either an increase in work performed on an ergometer (rowing or cycle) or an increase in velocity in rowing, skiing or running. Again, this procedure is not preferred but it does provide some information which is of practical assistance, particularly during training. This assistance will be explained in the next section.

5.0 TRAINING METHODS

The FISA CDP has emphasized the importance of training the aerobic metabolic system as this system provides about 75-80% of the energy needs of the body during a rowing race. In BASIC ROWING PHYSIOLOGY, the following training advice was presented:

1. To improve oxygen utilization: long distance training (at a heartrate of 130-160 beats per minute and below anaerobic threshold).

2. To improve oxygen transport: interval training (at a heartrate of 180-190 beats per minute and above anaerobic threshold).

The results of training the aerobic metabolic system is illustrated in figure 11.

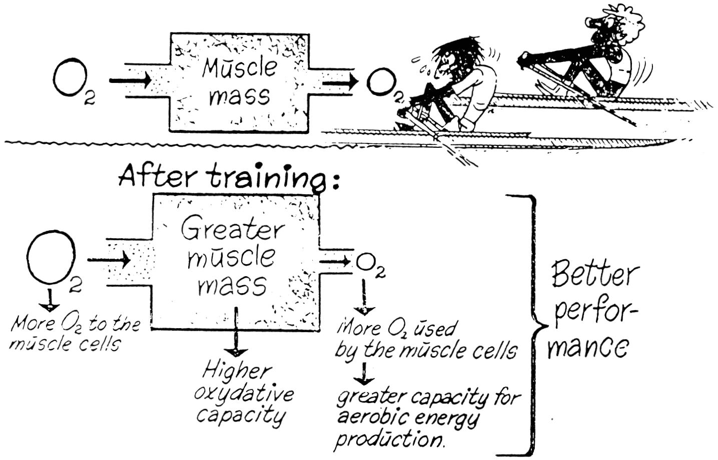


Figure 11. The Results of Aerobic Training

Although the lactic anaerobic metabolic system accounts for only 20-25% of the energy requirements during a rowing race, it plays a crucial role during the start and finish phases of the race. Further, as stated in section 3.4, a purpose of training is to be able to use a greater percentage of the maximum oxygen uptake before obtaining significant increases in lactate concentrations. The training methods that most effectively influence these factors appear to be:

1. Training at or near the anaerobic threshold point improves the body's ability to utilize a greater per centage of the VO2 max. before the onset of lactate accumulation.

2. Interval training at high training loads with sufficient rest periods to remove all or most of the accumulated lactate improves the body's ability to tolerate lactate accumulation.

Since the alactic anaerobic metabolic system accounts for limited contribution to the energy requirements of the rowing race, the training of this system is generally restricted to late in the season and may be accomplished by multiple intermittent work periods of 10-15 seconds with recovery periods of 30-60 seconds between each work period.

Further information about training methods for these systems is presented in the booklet titled SPECIFIC FITNESS TRAINING of the FISA CDP Level II programme.

6.0 SUMMARY

You should now have expanded your understanding of the physiological requirements of the sport of rowing. With this information, you will be able to provide better assistance to your athletes in the design and implementation of training programmes.

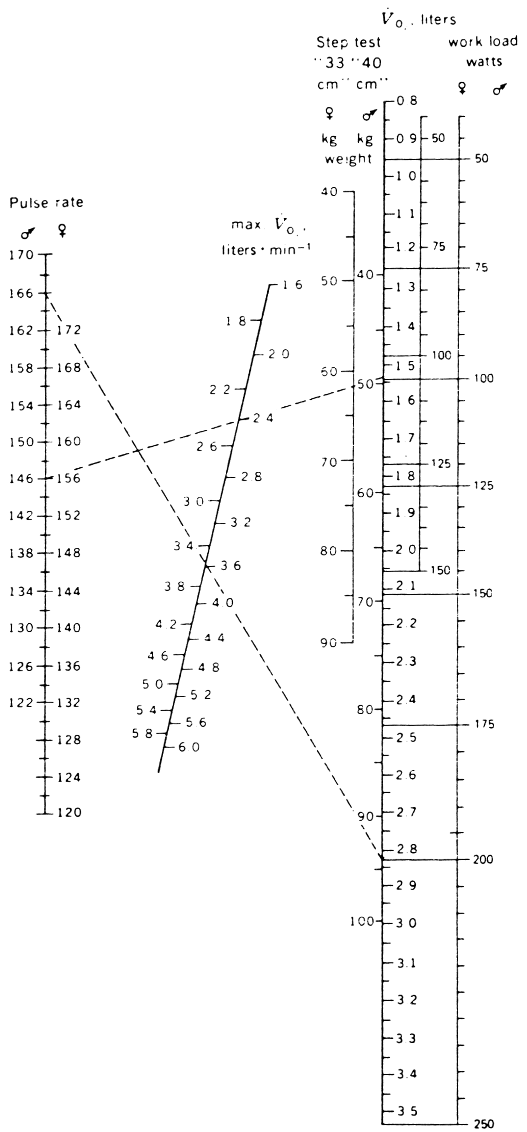
7.0 APPENDICES

7.1 Appendix A. Astrand Nomogram

Adapted from Textbook of Work Physiology, 2nd ed., by Per-Olof Astrand and Kaare Rodahl from McGraw-Hill Book Company. 1977.

7.1 Appendix A. Astrand Nomogram

Adapted from Textbook of Work Physiology, 2nd ed., by Per-Olof Astrand and Kaare Rodahl from McGraw-Hill Book Company. 1977.



The adjusted nomogram for calculation of maximal oxygen uptake from submaximal pulse rate and 02-uptake values (cycling, running or walking and steptest). In tests without direct 02-uptake measurement, it can be estimated by reading horizontally from the "body weight" scale (step test) or "work load" scale (cycle test) to the "02-uptake" scale. The point on the 02-uptake scale (V02 liters) shall be connected with the corresponding point on the pulse rate scale, and the predicted maximal 02-uptake read on the middle scale. A female subject (61 kg) reaches a heart rate of 156 at step test: predicted max V02 = 2,4 liters min. A male subject reaches a heart rate of 166 at cycling test on a work load of 200 watts; predicted max V02 = 3,6 liters min (exemplified by dotted lines).
(From I. Åstrand, 1960)