2 Intermediate Rowing Physiology

2.1 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.

2.2 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 forwards across the surface of the water by an athlete seated in the boat and moving forwards and backwards 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

\[
\text{WORK} = \text{force} \cdot \text{distance} \\
\text{POWER} = \frac{\text{force} \cdot \text{distance}}{\text{time}} \\
\text{POWER} = \text{force} \cdot \text{velocity}
\]
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)
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.

2.3 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.

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 resynthesise 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 2,000m rowing race.
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 utilised primarily during the start and finish phases of the race.

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

Aerobic metabolism

Aerobic metabolism provides about 75% to 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 utilised.
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.


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: Anaerobic threshold](image-url)
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. Nagerman*

<table>
<thead>
<tr>
<th>DEC.</th>
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<td>ml/kg/min.</td>
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<td>A.T. (%)</td>
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<td>$VO_2 - A.T.$</td>
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<td>4,27</td>
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<tr>
<td>Watts</td>
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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.

### 2.4 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.
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, and
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 workloads and those extrapolations to maximal workloads can be made to estimate or predict VO2 max. Two predictive tests are the:

1. Step test:
   a test requiring a step up to and step down from a bench (33cm and 40cm 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. 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.
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 heart rate 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.
### Figure 8: Testing results / lightweight men

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| Time | Work | HR | BF | RQ | EQ- | VE | Vo2 | Vo2/mL | MET | Vo2/kg | VCo2 | P20 | Eq-  | VE | Vo2 | Vo2/mL | MET | Vo2/kg | VCo2 | P20 | Eq-  | VE | Vo2 | Vo2/mL | MET | Vo2/kg | VCo2 | P20 | Eq-  | VE | Vo2 | Vo2/mL |
|------|------|----|----|----|-----|----|-----|-------|-----|--------|------|-----|-----|----|-----|-------|-----|--------|------|-----|-----|----|-----|-------|-----|--------|------|-----|-----|----|-----|-------|-----|--------|------|-----|-----|----|-----|-------|-----|--------|------|-----|-----|----|-----|-------|-----|--------|
| 0:30 | 350 | 168 | 39 | 0.90 | 38 | 109.1 | 3.18 | 46.0 | 13.4 | 0.28 | 2.08 | 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 | 51 | 0.91 | 34 | 149.9 | 4.80 | 70.5 | 20.2 | 0.39 | 4.37 | 3.70 | 31 |
| 2:00 | 360 | 178 | 62 | 0.95 | 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 | | | | | | | | |

Max: 403 183 105 1.11 42 233.7 5.24 77.1 22.0 0.42 5.73 3.76 47

Fred: 196 197.5 3.53 46.5

%Pre: 93%

148 148 159

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### Figure 9: Testing results / senior women

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<tr>
<td>Geschlecht(M/F):</td>
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<td>P20 (€):</td>
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</table>

| Time | Work | HR | BF | RQ | EQ- | VE | Vo2 | Vo2/mL | MET | Vo2/kg | VCo2 | P20 | Eq-  | VE | Vo2 | Vo2/mL | MET | Vo2/kg | VCo2 | P20 | Eq-  | VE | Vo2 | Vo2/mL |
|------|------|----|----|----|-----|----|-----|-------|-----|--------|------|-----|-----|----|-----|-------|-----|--------|------|-----|-----|----|-----|-------|-----|--------|
| 0:30 | 300 | 154 | 63 | 1.04 | 43 | 75.3 | 1.70 | 21.6 | 6.2 | 0.14 | 1.76 | 2.95 | 44 |
| 1:00 | 308 | 171 | 63 | 0.81 | 42 | 133.6 | 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 | 140.7 | 3.94 | 50.6 | 14.4 | 0.30 | 3.78 | 3.44 | 36 |
| 2:30 | 291 | 172 | 63 | 0.99 | 37 | 141.3 | 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 | 301 | 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 | 151.7 | 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 |
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| 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 | | | | | | | | |

Max: 300 179 67 1.04 43 159.2 4.26 54.6 15.6 0.31 4.37 3.60 44

Fred: 194 143.5 2.25 38.8

%Pre: 92

111 189 141
Testing of anaerobic threshold

Anaerobic threshold, as explained in section 3.4, is a metabolic response to an increasing workload 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 workloads. (The volume of air going into and out of the lungs is called ventilation.)

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

The increasing workload 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.
2.5 Training methods

The FISA CDP has emphasised the importance of training the aerobic metabolic system as this system provides about 75% to 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 utilisation: long-distance training (at a heart rate of 130 to 160 beats per minute and below anaerobic threshold).
2. To improve oxygen transport: interval training (at a heart rate of 180 to 190 beats per minute and above anaerobic threshold).

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

![Diagram of aerobic training results](image)

Figure 11: The results of aerobic training

Although the lactic anaerobic metabolic system accounts for only 20 to 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 utilise a greater percentage 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 to 15 seconds with recovery periods of 30 to 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.

2.6 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.

2.7 Appendices

Appendix A. Astrand nomogram


The adjusted nomogram for calculation of maximal oxygen uptake from submaximal pulse rate and O2 uptake values (cycling, running or walking and step test). In tests without direct O2uptake measurement, it can be estimated by reading horizontally from the “body weight” scale (step test) or “workload” scale (cycle test) to the “O2-uptake” scale. The point on the O2 uptake scale (VO2 liters) shall be connected with the corresponding point on the pulse rate scale, and the predicted maximal O2-uptake read on the middle scale. A female subject (61 kg) reaches a heart rate of 156 at step test: predicted max VO2 = 2.4 liters min. A male subject reaches a heart rate of 166 at cycling test on a workload of 200 watts; predicted max VO2 = 3.6 liters min (exemplified by dotted lines).
(From L. Åstrand, 1960)