TRAINING THE ENERGY SYSTEMS: Part I
By Dr. Fritz Hagerman

Dr. Fritz Hagerman, a world-renowned expert in exercise physiology, has been educating and improving rowers and coaches for over 30 years. Fritz's groundbreaking research in rowing physiology began in the late 60s with New Zealand's National team, and he has continuously worked with the U.S. National team since 1972. The results of his research have positively impacted the performance of our national teams by teaching athletes how to improve their training regimens as well as helping coaches to identify those with the best physiological potential. He has been working closely with U.S. Men's Coach Mike Teti since 1997. Fritz is a Professor of Physiology at Ohio University and also serves as the Head of FISA's Sports Medicine Commission. irow.com is extremely honored to have "THE MAN" in rowing physiology share his knowledge with us.

It was emphasized in "Defining the Energy Systems" that the interaction among the three energy systems - ATP-PC and Lactic Acid Systems (anaerobic), and the Oxygen System (aerobic) - during rowing training and competition represents several complex biochemical processes. It should, therefore, be of no surprise to any of our previous or more recent on-line viewers to learn that it is difficult to blend these three systems into an effective training program that will maximize the use and development of each system and result in improved rowing performance.

Before discussing specific recommendations to improve the effectiveness of each energy system, it is important to review the basic principles of training. Training should be mostly task specific, and when not rowing, the athlete should exercise to simulate the rowing stroke, whether in part or as a whole, including resistance or weight training.

The only exceptions would be off-season cross-training or alternative training due to an injury caused or aggravated by rowing. Overload the physiological systems, but don't concentrate this overload; follow the 10% rule when starting a training program, meaning an increase of no more than 10% per week in training frequency, duration, and intensity. As training progresses, then the weekly increase can be reduced to as low as 5%.

Also, don't forget that rest and recovery are vital ingredients in the best training recipe; a failure to plan for these can produce disastrous results, including peaking at the wrong time, overtraining, or chronic fatigue. Remember, under-training is usually never a problem for the motivated rower. If you are unusually tired, injured, or sick, then taking a day or two off should not be considered a serious training set-back. Instead, abstinence of training under any of these conditions is a wise choice. Because most interruptions of training are due to respiratory infections, it is recommended that training be reduced if the respiratory problem is above the neck and cancelled if it is below the neck.

Consistency of training is one of the most important training principles; you must use it, or lose it, and as you know, it is far easier to maintain a highly trained state than to achieve one. Individualize your training program based on your skill and fitness levels, availability of training facilities and equipment, and the amount of time you have available. There is no "best time" of the day to train, as it has been shown conclusively that the body doesn't "care" when you decide to train. However, very early morning time (1-4am) and training immediately before bedtime or following a large meal should be avoided. An increase in training should also be accompanied by an increase in the quantity and quality of food intake, a higher intake of calories will be necessary to fuel the energy systems.
Training the Energy Systems
Part II: Peaking
By Dr. Fritz Hagerman

Probably the most difficult job for any coach or self-trained athlete is to design a training program that will permit “peaking” at the right time. This goal is sometimes further complicated by the need to “peak” more than once in a period of only a few months which is often the case of U.S. Olympic qualifiers.

Successful and competitive performances are dependent on carefully planned comprehensive training programs that usually span several weeks or months including up to a year or more. Periodicity of training provides planning for long-term periods (macrocycles) which, in turn, are divided into number of training sessions, days, or weeks (microcycles).

Macrocycles are often represented by an out-of-competition period, a preparation period, and a competitive period and for rowers who live north of the equator, these periods would include approximately September through December, January through April, and May through August respectively. Furthermore, training can be categorized as either specific or non-specific. Specific training includes all work done on the water, rowing ergometry, and tank exercises whereas non-specific (supplemental) training can include weight training, flexibility exercises, or any form of cross training such as cycling, swimming, running, or cross country skiing.

A well-planned training program is based on four specific training factors: type of training (specific and non-specific), frequency (number of sessions per day, week, or cycle), duration (length of time for each training session), and intensity of training (rate of doing work). The intensity of work is the most critical factor in planning a program which will culminate in your best performance. It is well known that the timing of increasing or decreasing intensity determines whether an athlete “peaks” at the desired time or not. In addition, if intensity is increased at too high a rate it can lead to overtraining, injury, and fatigue. The selection of the right mixture of the four training factors is the basis of successful conditioning.

As you train it is good advice to learn and remember how the body responds to exercise and as you plan a training schedule, record it (computer, audio, or written); don’t go on the water, enter the weight room, or sit on the ergometer without a plan. When you complete each training session, again record what you have done, compare the results with your intended plan, and immediately note how your body reacted to the training session. Modifying or changing training programs may be necessary and comparing your specific training regimens with your competitive performances over time will permit you to more objectively make accurate modifications.
Although certain training recommendations will tend to benefit one energy system more than another, their close relationship insures an energy continuum. Despite emphasizing one energy system with a specific training stimulus, it is likely you will always have some overlap among systems, especially when you consider the variable time frames and weather conditions in which rowing, training, and competition take place.

It is also important to point out that there are a number of different ways to train each of the energy systems and a wealth of training information is now available in several different forms; video and audio tapes, the internet, live symposia, and the old stand-by, the written word. If anything, hopefully the information presented here will help you to make better and more intelligent training choices.

You may recall the description of the three energy systems available to the rowing muscles from the previous presentation on this website; the ATP-PC System, the Lactic Acid System, and the Oxygen System. With the exception of the few seconds of an exercise when our muscles must rely on the ATP-PC System for energy, the use of the other energy systems depends on the duration and intensity of the exercise.

The Adenosine Triphosphate-Phosphocreatine (ATP-PC) System

Because of only a limited contribution of this system to rowing and because it is used most effectively during the first few seconds of any exercise, it is not necessary to devote much of your training time, if any, to the improvement of this system. Our earlier research indicated that this system contributes less than 5% of the energy needed to row a highly competitive 2000m race.

Recent research seems to tell us that insignificant changes occur in this system despite regular performance of high intensity bouts of exercise that last between 5 and 15 seconds. If you want to train the ATP-PC System, it is suggested that multiple intermittent work bouts of less than 20 seconds be performed, e.g., racing starts, with recovery periods of 40-60 seconds between each work bout. In this way the work bouts are too brief to provide much stimulation to anaerobic glycolysis (Lactic Acid System), and the relative long recovery periods permit adequate restoration of ATP and PC. This also means less lactic acid is produced, thus lowering the prospect of acute fatigue associated with this by-product of anaerobic metabolism. Training at or greater than 100% of maximum effort (see accompanying training intensity table) will stimulate this energy system.

Although some athletes appear to be blessed with more powerful ATP-PC systems, the quickness and explosiveness of a rower are also determined by other factors such as muscle fiber type distribution and complex neuromuscular relationships. There is no difference in the biochemical machinery of this system between men and women, however, men tend to have higher absolute energy outputs because of their larger skeletal muscle mass. To suggest that a rower cannot get faster or react more quickly, with training, is incorrect, but it would be more productive to concentrate on developing skill and technique at higher velocities than
attempting to design training sessions concentrating solely on improvement of the ATP-PC System.

It is interesting to note that probably the most widely used ergogenic aid in sports today is phosphocreatine (PC). This compound has gained popularity because it is not found as part of any sports federation banned or illegal substance list, it is suggested to be effective in improving performance, and, at least for now, there appears to be no known acute or chronic side effects. If PC is effective, then it would be for only short periods. A recent avalanche of reports concerning PC has tumbled out of both the scientific and non-scientific communities, and the results are equivocal.

Although short bouts of repetitive muscular efforts have been shown to improve using isolated muscle groups as a result of PC ingestion, sports performances following PC use, both actual and simulated, are less impressive. There seems to be a strong relationship between the amount of PC stored in the working muscle and the ability to perform repetitive anaerobic work bouts, but it is difficult to assess the PC storage capacity or content of muscle and this capacity and content apparently vary from one individual to the next. PC may be similar to our electrolyte use; if we are low in calcium then exercise performance may be impaired.

However, it would be unwise to simply consume large amounts of calcium without knowing what its concentration is in the body; calcium is relatively easy to measure in the body, PC is not. There are also no reports of the long-term effects of PC use and it will be some time before these data are available. Although the distributors of PC are recommending that all sports will benefit from its use, there is no reliable evidence that this is the case and nor is there valid evidence that increased muscular concentrations of PC spare or delay the use of the other energy systems, thus contributing to a possible larger and more efficient energy pool.
Training the Energy Systems
Part IV: Anaerobic Glycolysis – Lactic Acid System (LAS)

Although this energy system accounts for only about 15 to 20% of the energy contribution during a 2000m race, the timing of its contribution is critical. Because elite rowers generate their highest power outputs in the first 500m of a race, significant amounts of lactic acid are produced during the first 90 seconds. In fact, our research has shown that blood lactate concentrations reach maximal levels within the first 2 minutes of a 2000m race.

Therefore, the rower usually tolerates a very high lactate load for an additional 3-4 minutes until the sprint, when the Lactic Acid System is once again challenged to make a significant energy contribution. Venous blood lactate values in excess of 20 mmol/L of blood have been observed for elite rowers following 2000m competitive efforts and, when compared with responses of elite aerobic athletes in other sports, the rower’s responses have been among the highest. As a result, one can appreciate the physical discomfort a rower experiences during and immediately following a race.

It is important to note that measuring blood lactate does not reflect the total amount of lactate produced by the working muscles. Instead it is more of a residual concentration of lactate left over following a complex series of biochemical cellular reactions that involve lactate production, transport, clearance, buffering and resynthesis to ATP and glycogen. Maximal lactate concentrations are quite variable among individuals, but tend to be more consistent following submaximal efforts. The Lactic Acid System’s (LAS) range of maximum energy production is 60-90 seconds during high intensity exercise.

Although there are several training schemes designed to improve this energy system, it is recommended that any training intensity above anaerobic threshold (AT) will improve the LA System (see intensity table). There is also evidence to indicate that this system, among the three energy systems, probably has the greatest capacity to change with training. Repeated rowing efforts of 1-3 minutes above AT and using a work:recovery ratio 1:3 or 1:2 will permit sufficient time for large amounts of lactate to be cleared and resynthesized.

In other words, if you row 3 minutes, then your recovery time between exercise bouts will double or triple the exercise time. This is not only an effective way to train the Lactic Acid System, but if exercise duration is extended, the cardiovascular transport system will also greatly benefit. Any work performed at or above AT will teach the athlete lactate tolerance and, as the exercise increases in intensity, so will the learning effect. The AT seems as receptive to change as the LAS.

It is not uncommon for an elite rower to improve AT from 70-75% of maximal heart rate during the off-season to 85-90% during the competitive period. Anaerobic Threshold training should include a work:recovery ratio of 1:1. Because training intensities above AT are almost totally dependent on glucose and glycogen for fuel, it is recommended that 36-48 hours should separate any of these higher intensity workouts. Even a diet high in carbohydrate will be challenged to replenish muscle glycogen stores during these recovery times. I have often referred to AT as that point during high intensity exercise where an untrained person will stop exercising and where a trained athlete will begin to think about quitting; the latter being precisely the state of mind you want your opponent to be in with 250-500m to go in the race.
The Oxygen System, or aerobic metabolism, makes the most significant contribution of energy during a 2000m race and also for most training rows. Although more active biochemical changes seem to occur in the muscle cell as a result of aerobic training compared to only minimal changes attributed to anaerobic training, the actual increase in VO₂ max is proportionally less than measurable responses of anaerobic factors due to specific training methods. Although it appears that VO₂ max is primarily determined by hereditary factors, it can be significantly improved with training. However, its capacity for change is considerably less than the potential for change in the anaerobic response.

For many years, exercise scientists have suggested that VO₂ max is the single most limiting factor in performing high intensity aerobic work that extends beyond 3 minutes. Although there is a strong relationship between VO₂ max and a rower’s performance, our more recent research has shown that there is an even stronger relationship between a rower’s ability to work for 5-7 minutes at a higher percentage of their VO₂ max and their performance.

The most revealing physiological response to predict rowing performance at the international level is the rower’s ability to maintain their metabolic rate at or above AT. Any aerobic athlete who can significantly elevate their AT can perform high intensity exercise more efficiently (aerobic metabolism means more ATP molecules) and the by-products of the O₂ system, CO₂ and H₂O, are easy to deal with. This is not the case when anaerobic metabolism dominates.

Oxygen, or aerobic training, can be divided into either high intensity or low intensity workouts and both can use either continuous or intermittent training sessions. High intensity aerobic training seems more conducive to intermittent work, which should range from about 75-90% of maximal heart rate (see table of training intensities) with a work recovery ratio of either 1:0.5 or 1:0.25. In other words, if you row 10 minutes in this intensity range, your recovery period should range from 2.5 to 5 minutes. The high intensity form should not only represent the majority of your aerobic training but should also be the largest contributor to total training time.

Most low intensity aerobic training should be continuous and, if done intermittently, it should not be for any length of time less than 10 minutes. Rest or recovery periods for low intensity aerobic rowing should range between 30-60 seconds; the shorter the duration of exercise, the shorter the recovery period needed. Low intensity aerobic training is often referred to as “conversational” pace and thus you should be able to talk easily during an exercise of this intensity.

Although both forms of aerobic training permit a rower to reach and maintain an aerobic base, do not interpret the value of aerobic training in only quantitative terms. Every workout, even of a low intensity, must always stress quality, and as the physical condition of the rower improves, both exercise intensity and skill level need to be elevated. Many coaches and athletes are convinced that 60-120 minutes of continuous low intensity or steady-state rowing is an important part of developing and maintaining an adequate aerobic base. We have convincing data, including muscle biopsy histochemical and biochemical indicators, which support that rowing continuously at a low steady state intensity for 60
minutes or longer for any calibre of rower, is not more effective in maintaining aerobic capacity than 30 minutes of rowing at the same work intensity.

Not only do these results apply to a single bout of rowing, but also to 5, 10, 15, and 20 week training responses after the aerobically-trained subjects had completed a total of 20, 40, 60 and 80 training sessions respectively. Furthermore, performing 2 intermittent 30 minute exercise bouts of relatively high aerobic work intensity (10-20% more average power than for the low intensity work) with a 7-10 minute recovery period between the 30 minute work bouts is a much stronger aerobic training stimulus than lower intensity continuous rowing.

This higher work intensity for continuous rowing could not be tolerated by most subjects for more than 32-36 minutes and still maintain a steady-state. The increased energy expenditure of the intermittent high intensity work not only proved significantly more effective than either 30 or 60 minutes of rowing in the improvement of aerobic capacity, but it was also more neuromuscularly task specific.

Comparative videotape, coaching evaluations, and metabolic data confirmed those rowers performing intermittent high intensity training bouts rowed more efficiently at all exercise intensities than those rowers who trained for longer time periods and at lower intensities, especially as stroke rating and power output increased to beyond AT, including maximum power output.

This presentation has discussed training of all three basic energy systems, including AT training with supporting research data to validate my recommendations. Regardless of your present skill level or physical conditioning state or your competitive aspirations, optimal training of the energy systems requires a comprehensive training program. In future irow.com presentations, the importance of comprehensiveness will be emphasized by discussions dealing with such topics as resistance training, cross training, artificial and actual altitude training, restricted breathing training, high oxygen training, ionization training, electrical stimulation of muscle, and muscle and blood boosting using creatine, human growth hormone, erythropoietin (EPO), and oxygen “kickers” such as flurocarbons, oxygen breathing, and oxygenated water.
## Training Intensities

<table>
<thead>
<tr>
<th>Training Intensity</th>
<th>Energy System *</th>
<th>Type of Training</th>
<th>Optimal Time</th>
<th>Work: Recovery Ratio</th>
<th>%Max Effort</th>
<th>%HR Max</th>
<th>HR Range** (b/min)</th>
<th>Lactate Range (mmol/L)</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaerobic I (AN₁)</td>
<td>ATP-PC</td>
<td>All out sprint</td>
<td>10 - 30 sec</td>
<td>Complete recovery</td>
<td>95-100</td>
<td>95-100</td>
<td>180-190</td>
<td>Small amount</td>
<td>Preferential energy fuels are stored PC and ATP in muscle; muscle fiber recruitment always begins with Type I (slow twitch) followed quickly by Type IIa (fast oxidative) and Type IIb (fast nonoxidative) with emphasis on Type II fibers.</td>
</tr>
<tr>
<td>Anaerobic II (AN₂)</td>
<td>LA</td>
<td>Short interval</td>
<td>30 - 90 sec</td>
<td>1:3</td>
<td>90-95</td>
<td>90-95</td>
<td>170-180</td>
<td>Maximum values (10-30)</td>
<td>Highest rate of anaerobic glycolysis; blood glucose and some muscle glycogen are preferred energy sources; recruitment pattern of muscle fiber types is same as AN₁ and increases occur in muscle anaerobic enzymes and there is improved buffering power of muscles and blood.</td>
</tr>
<tr>
<td>transportation(TN)</td>
<td>ATP-PC LA O₂</td>
<td>Moderate interval</td>
<td>90 sec - 5 min</td>
<td>1:2</td>
<td>85-90</td>
<td>85-90</td>
<td>165-170</td>
<td>6-10</td>
<td>Slightly lower exercise intensity than AN₂; utilizes primarily glycerol from muscle and liver for shorter work bout and incorporates more O₂ as work time is extended; excellent stimulation of cardiovascular delivery apparatus and improves VO₂ max; all muscle fiber types will be used if intensity and exercise duration are increased.</td>
</tr>
<tr>
<td>Anaerobic Threshold (AT)</td>
<td>LA O₂</td>
<td>Long interval</td>
<td>5 – 20 min</td>
<td>1:1</td>
<td>80-85</td>
<td>80-85</td>
<td>155-160</td>
<td>4-6</td>
<td>This is very hard work and probably cannot be sustained much longer than 20 min without onset of fatigue; cellular O₂ transport becomes a problem; major source of energy is glucose and glycogen with some fatty acid metabolism during longer work bouts; emphasizes use of fiber types I and IIa.</td>
</tr>
<tr>
<td>Utilization 1 (U₁)</td>
<td>O₂ LA</td>
<td>Continuous work or Long interval</td>
<td>10 – 30 min or 1:0.5</td>
<td>75-80</td>
<td>75-80</td>
<td>145-155</td>
<td>2-4</td>
<td>Primary objective of this intensity is to cause muscle to use oxygen more efficiently; should make up bulk of total training; Types I and IIa muscle fibers are used preferentially; although glycogen is used for energy, use of fatty acids becomes more important.</td>
<td></td>
</tr>
<tr>
<td>Utilization 2 (U₂)</td>
<td>O₂</td>
<td>Continuous</td>
<td>30 – 60 min</td>
<td>Continuous</td>
<td>65-75</td>
<td>65-75</td>
<td>125-145</td>
<td>2 or less</td>
<td>Uses continuous or interrupted exercise of long duration; major energy source is free fatty acids with some glycogen use; emphasizes Type I muscle fibers; often referred to as conversational pace.</td>
</tr>
<tr>
<td>Utilization 3 (U₃)</td>
<td>O₂</td>
<td>Continuous</td>
<td>60 - 120 min</td>
<td>Continuous</td>
<td>50-65</td>
<td>50-65</td>
<td>95-125</td>
<td>Very small amounts</td>
<td>Lowest level of aerobic stimuli; recommended for non-competitive recreational athletes; can maintain minimal fitness requirements; energy source is primarily free fatty acids; uses Type I and some IIa fibers.</td>
</tr>
</tbody>
</table>

* Energy System:
  - ATP-PC: Adenosine Triphosphate-Phosphocreatine
  - LA: Lactate
  - O₂: Oxygen

** HR Range:
  - HR: Heart Rate

** Lactate Range:
  - mmol/L: Millimolar Per Liter