PHYSIOLOGY OF SPEED SKATING

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PREFACE

This is a monograph for coaches. It is an attempt on our part to translate research into the physiology of speed skating that we have conducted over the last decade into the practical, if cold, world of the club coach. Beyond your job of teaching the skill of ice skating and the unique variation of ice skating technique necessary to go fast, you have to understand what is happening in the body of your athletes. Why do some skaters go faster than others?, what happens during different types of training sessions?, why do skaters get tired?, do the East Germans really have a secret weapon in their sports science techniques?

In science, as in no other area, we stand on the shoulders of giants. The idea for this monograph was inspired by a series of monographs published in Sweden in the late 1960's that dealt with the physiology of several sports. Monograph number 5 in this series "Hastiegning pa skridrisko" dealt with speed skating. It's authors, Bjorn Ekblom, Lars Hermansen and Bengt Saltin, have done much to define exercise physiology as an academic discipline. Additionally, much of the contemporary work with speed skaters has been done at the Free University of Amsterdam. The scientists there certainly deserve credit for the work they have done, and for first proposing many of the ideas incorporated in this monograph.

It may be useful for you to understand a little bit about us, and how we came to write this monograph. None of us are, historically, speed skaters. I (CF) grew up in Dallas, TX. In geographical terms, that's like growing up in Cairo, Egypt. The weather's not much different either. Down there if there is ice outside, you stay inside for the few hours until it goes away. We were running a Cardiac Rehabilitation Program at Mount Sinai Medical Center in Milwaukee, when Peter Schotting showed up on the door step one day with a peculiar looking group of athletes. We thought they were like 5000m runners, such was the status of the scientific literature on that popular American sport, speed skating. Needless to say we didn't do much that was useful, but we found out that the skaters were among the nicest athletes we had ever worked with, and we found the sport intriguing. Along the way we picked up a couple of colleagues who, if not quite as intrinsically unprepared, came close seconds. One (AS) has a historical interest in going fast on ice (the unfrozen kind in college swimming pools). The other (NT), at least has a father who was a speed skater, and Norwegian genes. The point of this is that much of what we have done has been overcoming our own ignorance and lack of visceral understanding of the sport and, perhaps, in challenging some of the old assumptions of those who grew up in the sport.

A decade later, we're still here. There still isn't much in the scientific literature, and what's there is largely written by and for the specialists. It's jargon that is largely unintelligible to anyone standing on the ice yelling "build it". Beyond Dianne Holum's book and the monograph of the Swedes (written in 1967 in Swedish), there isn't much (in English) for coaches to read that's specific to speed skating. There is an excellent Dutch book, Handboek Wedstrijd-Schaatsen edited by Henk Gemser and Gerrit Jan van Ingen Schenau, but with American linguistic skills being what they are, not many can read it. Hopefully this monograph will begin to bridge that gap.

The work that made this monograph possible was sponsored by research and service grants from the Sports Science Division of the United States Olympic Committee and from Ross Laboratories, Columbus, OH. Sadly, just as we learned enough to be useful to skating coaches, the USOC eliminated its extramural sports science budget and Ross Laboratories decided to stop sponsoring "minor" sports. One hopes that wiser heads will eventually prevail within the USOC, USISA or industry and that funding for our active participation with coaches will again be available. In the meantime, hopefully this monograph will provide you with some insight.

Thanks obviously are due to a lot of coaches, athletes, and parent volunteers. If we listed everyone who helped us understand our own data (and some of you might be surprised at your contributions), you would have a roster of half the people in skating. Suffice to say that the biggies are those who have spent lots of hours

with us, answering the same dumb questions time and time again, trying out some dumb, and some not so dumb, hypotheses, and putting up with limited short term results in hope of making the sport better. They are, at the least: Paul Bader, Bob Fenn, Mike Crowe, Dianne Holum, Dan Immerfall, Susan Sandvig, Peter Schotting, Nancy Swider-Peltz and Mike Woods, MD. Thanks guys.

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INTRODUCTION

In speed skating the primary competitive criteria is getting from point A to point B in the shortest possible time. To a physiologist, this means that speed skating is an energy demand sport. Accordingly, one thinks about the physiology of speed skating in the same way as one thinks about other energy demand sports--running, cycling, rowing, cross country skiing. Energy demand sports follow a general model of performance which may be abbreviated by the following equation:

$$\text{SPEED} = \frac{\text{POWER OUTPUT} \times \text{EFFECTIVENESS}}{\text{RESISTANCE}}$$

Power output is, of course, the main interest of physiologists. How much muscular power can be liberated during the course of the race, how does it change with training, how can it be changed with other interventions such as dietary supplements? Effectiveness is skill. It is the primary interest of coaches and, despite the excellent work of the biomechanists, is not quite yet practically applicable to coaches. Resistance relates to things that make it hard to move fast--ice friction, wind resistance.

CHARACTERISTICS OF SPEED SKATERS

Speed skaters can generally be classified as small, muscular athletes. Although its hard to think of Dan Jansen or Eric Heiden as small men, they certainly are small compared to most other elite athletes, and particularly other elite muscular athletes. The characteristic smaller size of speed skaters is partly a result of larger athletes being selected into the team sports. It is also related to physics. Imagine if you will, Tony Mandarich taking the first curve of a 500m on the Calgary Oval, or Jose Canseco in a short track race.

The single most remarkable thing about most speed skaters is the striking development of their thigh and hip muscles. Next to a horse jockey or a professional basketball player, a speed skater would probably be the easiest athlete to identify simply on the basis of how they look. For example, I first met Harm Kuipers, a Dutch physiologist (and 1975 World All Around Champion), at the swimming pool during an American College of Sports Medicine meeting. I remember thinking as he walked across the pool deck, just before being introduced to him, "that guy should have been a speed skater". Even 10 years after his World Championship, the results of his years on the ice were highly characteristic. Interestingly, most skaters legs really aren't <u>that</u> big compared to age and sex matched controls. The muscular part of their legs is bigger, but the fat pad overlying the muscle is smaller, so the leg is only slightly bigger than average. Most skaters, however, tend to have short legs and particularly short thighs, both of which make the girth of their legs look bigger than it really is. Short legs and a long trunk presents an aerodynamic advantage (provided you can position it correctly), so there is a certain selection for short legged skaters. Short thighs also present a less power requiring lever for the hip muscles when the skater is in the sitting position, so there is selection for short thighed skaters.

From the coaching perspective, selection of athletes is something that happens naturally. If you encounter long legged or long thighed skaters, don't discourage them. You might however, emphasize more of a tempo type style, since these athletes are unlikely to be as successful at trying to sit deep and push powerfully as so many of the role models do.

Speed skaters are usually fairly lean athletes. They are not, however, as lean as runners or gymnasts. Since skaters do not need to lift their center of gravity while skating, a little extra fat is less of a problem than it might be for other athletes. We generally recommend a range of body fat from 5 to 10 percent for senior men and 10 to 17 percent for senior women. Younger skaters are sometimes a little fatter than this. Unless it is a particularly obvious problem, we don't recommend dieting in young skaters who are still growing. This problem often corrects itself with continued participation in the sport. In any case, the less negative feedback the better We are just as interested in skaters who get too lean as skaters who are too fat. In our experience, getting too lean may be associated with loss of strength and the ability to recover from training.

We recommend particular caution when approaching female skaters about the need to loose a few pounds. Although a lean skater is almost always better, and many female skaters could profitably loose a few pounds, female athletes are particularly prone to develop eating disorders. A survey of female athletes performed at Michigan State University indicated that the start of the eating disorder was often an apparently innocent remark by dad or coach or boyfriend (or exercise physiologist)--taken way too seriously. If you think that one of your athletes has a problem in this area, approach it just as cautiously as you would a glaring personal problem that might provoke an emotional outburst when mentioned.

If you wind up an exercise physiologist and turn them loose, they will try to measure oxygen consumption during exercise. It's as fundamental as a skating coach saying "build it". Predictably, the single most commonly cited physiological characteristic of athletes is the maximal oxygen consumption (VO_2 max), aerobic power in conventional jargon. Since early studies of the Swedish National Teams conducted in the 1960's, VO2max has been known to be important to athletes in energy demand sports (Figure 1).

Elite nordic (cross country) skiers usually have VO2max values in excess of 80 and 70 ml/kg body weight for males and females, respectively. Speed skaters were fairly high within this grouping of Swedish athletes, with values averaging about 75 and 52 ml/kg body weight for males and females, respectively. By comparison, untrained men and women have VO2max values of about 45 and 35 ml/kg body weight, and the highest values reported in humans is on the order of 90 and 80 ml/kg body weight for males and females (in other cross country skiers). For perspective, the family beagle that you take jogging with you has a VO2max of about 130 ml/kg.

Studies with American speed skaters that we have performed over the last decade, suggest that VO2max is not nearly as high as in the Swedish National Team skaters studied earlier. We get averages of about 62 and 52 ml/kg body weight for males and females, respectively. We have only studied three individual American skaters who ever exceed a VO2max of 70 ml/kg body weight (Mike Woods, Kent Thometz and Dave Silk), and all three just barely exceed 70 ml/kg. Even Eric Heiden, surely the reference standard among speed skaters, only recorded 63.8 ml/kg in October 1979. It is arguable that Eric was in pretty good shape at this time. We believe that since American skaters are recruited from the sprint oriented pack style and short track events, we tend to select for a more sprint type athlete, with an intrinsically lower VO2max. Our subsequently better results in sprint events in international competition would support this notion. The Scandinavians and Dutch, on the other hand, tend to select from cross country skiers and marathon skaters and may wind up with a different type of athlete, usually successful primarily in longer events.

Several studies have shown that VO2max is higher in elite skaters compared to sub elite skaters (Figure 2). The differences are about 5% and probably reflect the combined effect of more years of systematic training, as well as some degree of selection for athletes with higher VO2max. The single exception appears to be among American female skaters. At this point, we are at something of a loss to explain this finding.

VO2max is classically measured during uphill treadmill running. This usually gives the highest value possible for any given individual. In well trained cyclists, VO2max while cycling is about the same as during uphill running. VO2max is generally about 80-90% of the running/cycling value while skating or exercising on the slideboard (Figure 3). This is because the skating posture and the characteristics of the skating stroke limit the amount of active muscle mass and the blood flow through the active muscles. During skating the leg muscles are contracted throughout much of the stroke, gliding and pushing. Blood flow through muscles is usually thought to be reduced when more than about 60% of maximal tension is generated. Since the isometric contraction of the leg during the gliding portion of the skating stroke is fairly high, its a safe bet that there is minimal blood flow during either the gliding or pushing phases of the stroke. It's hard for the muscle to consume oxygen if oxygenated blood has a hard time getting to the muscle cell. For us, this finding reinforces the modest importance of a really great aerobic power for most speed skaters. This is not to say that we wouldn't expect Thomas Gustafson or Yvonne van Gennip to have pretty awesome VO2max values, but rather that they are different types of skaters, from an entirely different skating tradition.

Skating is to a large degree an anaerobic sport. Certainly three of the primary metric distances can be completed by elite skaters in less than two minutes. This means that the oxygen transport system doesn't have time to make the kind of contribution it might in, say, the American Birkebeiner (a 55 km cross country ski race). Predictably, skaters generally have very high values for anaerobic power. Taking an anaerobic power test called the Wingate Test (sprinting all out on a cycle ergometer against a big gear for 30 seconds) the average power output for speed skaters is among the highest recorded by any group of athletes (Figure 4). The mean value for female skaters is above that of normal men. The high anaerobic power in skaters makes sense when you consider that 3 of the 5 metric events are basically sprints and that pack style and short track are sprinters sports.

Skaters are also very strong. Even though strength is harder to measure than other physiological characteristics, skaters are strong by any criteria one cares to use. In Figure 5 are mean values for knee extension torque (strength) on a Cybex (an isokinetic ergometer), for male and female skaters versus reference values for average men. As the speed of movement gets faster, the skaters become progressively relatively stronger. When you consider that knee extension velocity by elite skaters during skating is on the order of 600 degrees per second (much more explosive than we can measure in the laboratory) you can expect that skaters are indeed very strong.

Skaters are also particularly strong at joint angles where most people are very weak. The data in Figure 5, for example, represents peak torque at any joint angle within the extension of that joint. Most people are very weak at the joint angles associated with the beginning of the skating stroke. Since the Dutch have shown that the first 1/3 of the skating stroke is where power is generated, strength in the joint angles associated with the beginning of the stroke is particularly important. It's reasonable to suspect that skaters are relatively more different here than any place else. Its also reasonable to expect that better skaters are probably stronger-deeper more so than they are stronger-generally. There is preliminary evidence available from Greg Rajala at Marquette University suggesting that sprinters are stronger at the joint angles associated with the beginning of the skating stroke than are all-arounders, supporting this concept.

RESPONSES DURING COMPETITION

What happens when the gun goes off? Outside of getting very tired, what is the physiology of competition?

Oxygen consumption rises rapidly with increases in speed, but no so rapidly during speed skating as during running or hockey skating. For a given oxygen uptake, the speed requirements of skating are much higher (Figure 6). Data about the aerobic requirements of speed skating are somewhat limited since the technical requirements of measuring oxygen uptake are limiting at competitive speeds and because of the anaerobic contribution to skating even in longer events. Available evidence suggests (as you might expect) that bad ice increases and that drafting decreases the aerobic requirements of skating (Figure 7).

Cardiovascular responses are nearly maximal for all of the metric style events. Maximal heart rate is achieved by midway through most races (Figure 7). In pack style events, maximal heart rate is achieved only part of the time, usually when the skater has to work harder to lead the pack or to make a finishing effort.

Pulmonary ventilation (the amount of air breathed) is proportional to the momentary oxygen uptake (Figure 9). The relative ventilatory responses during skating are very similar to cycling or running at the same VO2. Accordingly, since the VO2max is slightly less during skating than during cycling or running, the maximal ventilation is slightly less.

Most of the action during skating takes place in the muscles. Because of the high metabolic rate required during skating and the poor blood flow through the partially contracted leg muscles, there is a particular premium on anaerobic metabolism during skating. This leads to substantial production, and accumulation, of lactate (lactic acid). Most of what we know about muscle lactate accumulation comes from studies done on non skaters on the cycle ergometer. As we shall see later, these studies are probably fairly representative of responses during skating.

Lactate is produced in muscle when the rate of degrading glycogen is so high that some of the end products of this degradation cannot be immediately used by the muscle. Lactate normally diffuses out of the muscle and is removed by other muscles, by the liver or by the heart. However, the rate of lactate production in the muscle can easily exceed the rate of lactate removal and lactate accumulates in the muscle. In Figure 10, we depict the relative accumulation of lactate in the thigh muscle during exhaustive cycling at rates sufficient to cause exhaustion within 30 seconds to 45 minutes. Because this figure is a synthesis of several studies, and muscle lactate is expressed in different units in different studies, we present the data as a ratio of immediately post exercise lactate to resting lactate. As can be seen, during high intensity exercise, muscle lactate accumulation is substantial. During more prolonged exercise, the net muscle lactate accumulation is less. This occurs both because the rate of lactate production is lower during less intense exercise and because there is time for diffusion of lactate out of the muscle to occur.

The diffusion of lactate out of the muscle occurs because the gradient (concentration difference) between muscle and blood pushes lactate from where it is more concentrated to where it is less concentrated (Figure 11). During a race, muscle lactate accumulates rapidly, and may reach very high values (~50 mM). During the race some of the lactate diffused out of the muscle into the blood, increasing the blood lactate concentration. After exercise, this diffusion continues so that the peak blood lactate concentration is reached 3-5 minutes after exercise. Depending on how muscle and blood concentrations are expressed, the peak muscle lactate concentration may be about twice as high as the subsequent blood lactate concentration.

During repeated efforts (or during more prolonged exercise), the magnitude of the gradient between muscle and blood lactate decreases and may even approach steady state conditions (Figure 12). In the example, we show the results of a one minute exhaustive cycle ride, repeated every 5 minutes. After the first couple of rides, muscle lactate changes very little. Blood lactate gets closer and closer to muscle lactate as the number of repetitions increases.

The rate of muscle and blood lactate accumulation parallels the intensity of exercise (Figure 13). This this example we plot muscle and blood lactate at exhaustion in work tasks requiring 2,6 and 15 minutes. In separate rides at the same intensity, the work was stopped and muscle and blood lactate concentrations measured in order to understand how muscle and blood lactate behave on the way to exhaustion. Beyond 6-8 minutes of work, the peak muscle lactate concentration is less. In more prolonged exercise the gradient between muscle and blood is smaller.

We haven't done biopsy studies in speed skaters, but there have been some studies done in hockey players during 60 minutes of continuous skating or during an interval session of 25 x 1 minute on, 1 minute off at a fast pace (120% VO2max) (Figure 14). Muscle glycogen, the primary fuel for muscular activity, is consumed very rapidly under both conditions. The decrease in muscle glycogen is more rapid during easy continuous skating than has been observed in cycling or running and even more rapid during interval skating than during easy continuous skating. The athletes achieved glycogen depletion (the wall in marathon runner jargon) after only an hour of intervals. Muscle lactate accumulates slowly during continuous skating, but increases very rapidly during interval skating. Other metabolites, such as CP, which are of great importance as immediate energy sources, decrease more during interval (fast) skating than during continuous skating. Interestingly, ATP (which is <u>the</u> immediate source of energy for muscular contraction) changes very little even during interval skating. This is the proof that the system works. Fuel (glycogen) is used, waste products (lactate) accumulate, secondary sources of energy (CP) decrease, but the immediate source of energy (ATP) is preserved. In physiology jargon this is called preserving homeostasis.

EXCEED AFTER ICE WORKOUT

STRETCH BETWEEN INTERVAL DRINK WATER ON-ICE.

As can be seen in Figure 15, during skating muscle lactate is about twice as high as the blood lactate concentration. The pattern of muscle and blood lactate concentrations is similar in this study with hockey players to that with cycling depicted in Figures 10, 12 & 13. At any given relative exercise intensity, blood lactate concentration during skating is higher than during cycling (Figure 16) A blood lactate concentration of 4 mM, which Swedish scientists have labeled OBLA (onset of blood lactate accumulation) occurs at about 75% of VO2max while cycling. During skating, this level of blood lactate accumulation is virtually assured once the skater "sits". These differences undoubtedly reflect the poor muscle blood flow during skating and the consequently higher muscle lactate concentration.

As might be expected from the foregoing, blood lactate concentration following speed skating races is fairly high. In Figure 17 we present post competition blood lactate values from several studies. In our experience, the highest blood lactate values are observed following 1000m and 1500m races, although they are high (>15 mM) for almost all competitions. In our experience, low post competition blood lactate concentrations are good evidence that the athlete is not getting enough carbohydrate in the diet to recover muscle glycogen adequately. As a point of reference, the highest post competition blood lactate we have seen was 24 mM in Bonnie Blair following a 1000m race. It's also fair to point out that we haven't measured post race blood lactate following really big races. The Swedes showed years ago, that post competition blood lactates were somewhat proportional to the motivation involved. Thus we'll take bets that following an Olympic or World Championships 1500m, blood lactate goes higher than 24 mM.

During competition blood lactate accumulates in a fairly linear manner from the beginning of the race to the end (Figure 18). We determined this several years ago during a simulated competitive race on roller skates at the USOC. We first had the skaters skate either 2000m or 3000m on rollers. We measured blood lactate at the conclusion of this simulated race. Blood lactate concentration was very similar to what would be expected for races of similar duration on the ice (3000-5000m). Then, in two separate, intermediate distance, trials we had the athletes skate at the same average pace they sustained during the simulated competition. We measured blood lactate at the end of each of these trials. Thus, we had the opportunity to see how blood lactate accumulated during a race without the necessity of stopping the competition itself.

From Figure 18 one can also see what happens when the skating pace is not relatively even. Some of the skaters started too fast and accumulated lactate quickly. They then had to slow down and let their lactate level drop so they could finish the distance. Others started conservatively and had fairly low lactates midway through the race. They then built up their pace, and their blood lactate responded accordingly. Is this why coaches are always yelling "build it"? These findings have always bothered us because of the great slow-down commonly seen during 1000m and 1500m races. We have always wondered whether it wouldn't be worth giving away a second or even two in the first 500m, if time could be made up later. One of our future priorities is to try some pacing studies in Calgary, where the environment can be controlled, or on the short track in a time trial mode. The coaches we have discussed this with have always been skeptical, claiming that there is more to be gained by building up speed early. Our data suggest at the least that this tactical approach needs to be examined experimentally.

The majority of the physiological responses during competition can be understood, by examining the relative exercise intensity versus the duration relationship (Figure 19). Generally, exercise intensities requiring an energy expenditure equal to VO2max can be sustained for about 10 minutes. Consequently, any event that can be completed in less than 10 minutes demands an exercise intensity greater than VO2max. Since almost all the metric style events require less than 10 minutes, that means that almost any speed skating race demands a considerable anaerobic energy contribution. For this reason, if no other, muscle and blood lactate become very important metabolites. In races that are skated pack style, tactical considerations may keep the average exercise intensity below VO2max for part of the race. However, these same races demand energy expenditures much greater than can be sustained by aerobic metabolism sometime during the finishing part of the race.

RESPONSES DURING TRAINING

A fundamental problem in the conditioning of athletes is to have enough general fitness to allow a fairly high volume of specific training. Specific training not only prepares the specific muscle fibers used in skating to work at the required power output, but also allows the skater to become more effective (to have better technique). This, accordingly, influences two components of the equation that determines speed.

For skaters there are two energy systems that need to be developed to allow for optimal performance, the aerobic and anaerobic energy systems. The aerobic energy system is that which depends on the effective delivery of oxygen from the outside air where it is readily available to the muscle cell where it is needed. The aerobic energy system demands the coordinated actions of the lungs, heart, blood, and blood vessels. Adequate development of the aerobic energy system is most probably what is meant by the general concept of "being in shape". The power of the aerobic energy system is best reflected by the VO2max. The anaerobic threshold is another marker of aerobic fitness which is the percentage (usually around 75%) of VO2max that can be sustained without the progressive accumulation of lactate. As already indicated, VO2max is not necessarily great in speed skaters. Never the less, adequate development of the aerobic energy system is generally very desirable, as it allows more work to be done without having to rely on the anaerobic system (and accumulating lactate). A well developed aerobic energy system also seems to be associated with a good capillary (small blood vessel) bed in the muscle, which enhances the removal of muscle lactate.

The anaerobic energy system is divided into the ATP-PC system and the glycogen degrading system. The ATP-PC system is a high power-low capacity system that is important during the first few seconds of exercise, particularly very high intensity exercise, such as the start. This system relies on energy stores-ATP & PC- that are stored in the muscle at rest and which are rapidly depleted with the start of exercise. Anaerobically, the glycogen degrading system has the capacity to sustain exercise for a couple of minutes, and is probably the most critical single system for speed skaters. The glycogen degrading system allows high intensity exercise to be performed at the expense of rapidly using up muscle glycogen and making lactate very rapidly. Both the power and capacity of this system may be changed with training. In the subsequent section on training, we will discuss different types of training, the physiological responses we have observed during monitored training sessions, and how the energy systems are likely to be influenced by that particular type of training.

Before embarking on a description of individual training responses, however, it is probably worth mentioning the concept of training thresholds. For training to produce adaptations, an overload must be applied. That is, the organism must be stressed beyond its momentary level of adaptation. There is a minimal level of stress, a threshold, beyond which the training effect begins to occur. The threshold may relate to any of the primary components of training-frequency, intensity, or time. Usually, intensity thresholds are of the most interest to coaches since they are the hardest to monitor--you know how many days per week and how many minutes per day your skaters train, but how hard are they training? It also relates to what we feel is one of the biggest problems in elite athletes--training too much, too easy.

There are two intensity thresholds that are particularly important. The first is the heart rate threshold first described by the Finnish physiologist Karvonen in the 1960's. Karvonen observed that if the intensity of training required the heart rate to change less than 60% of the difference between resting and maximal (the heart rate reserve), then minimal changes in VO2max were observed with the initiation of training in previously sedentary individuals. This concept, the target heart rate, has been well explored during the past two decades and the general belief is that for basic endurance training the heart rate should be somewhere between 70 and 85 % of the heart rate reserve. Generally the higher the intensity, the greater the effect on changes in VO2max, although beyond about 85% of the heart rate reserve, the duration of training is often so reduced that the benefit of training may be reduced.

The second concept of a training threshold is the idea of the anaerobic threshold. Properly speaking, the anaerobic threshold is a phenomena observed during graded exercise testing which is marked by the relatively abrupt accumulation of blood lactate and a disproportionate increase in the level of ventilation (breathing). During the sustained submaximal exercise that is typical for athletes in training, the intensity associated with the anaerobic threshold is often the highest exercise intensity that can be sustained without a progressive increase in blood lactate and early termination of the training bout because of fatigue from being out of breath and having burning muscles (Figure 20). Studies in Sweden, mostly with runners, have suggested that the intensity associated with the anaerobic threshold (or OBLA in the jargon the Swedes use) may be the best single training intensity, allowing a substantial amount of work to be done in a short period of time and allowing rapid physiological accommodation to the training stress. Although this concept has not been fully supported by experimental data, there is a widespread belief that an exercise intensity near the anaerobic threshold may represent the optimal training window for most general conditioning types of training. As we shall see later, high intensity interval sessions can even be managed so that from a metabolic standpoint they are anaerobic threshold sessions. This may allow the specificity of muscular action necessary to optimize training, and still allow for metabolic optimization. Certainly much of the work that we have done with the National Team during the last 4 years assumes that the concept of anaerobic threshold as the primary training window is correct.

DRY LAND TRAINING

Dry land exercises can be divided into two categories, those designed to promote general fitness and those designed to promote more or less specific adaptations as well as teaching skill elements.

RUNNING

Running represents one of the basic conditioning activities in that the load on the oxygen transport system is very efficiently applied. As such, there is as much if not more cardiovascular training during running as during any other type of training. There are several basic types of run training. Easy steady runs are useful for warm up and for general early season conditioning. If the athlete goes far enough, beyond 6-10 miles, these runs can become fairly demanding even though the pace isn't too fast. For most speed skaters, however, easy running should probably be used primarily for warm up/cool down. Most other run training should be more focused. There are three basic running workouts we recommend. The individual pace for each can be determined from the results of laboratory studies, or as a reasonable substitute from the results of a 2 mile time trial. These workouts are anaerobic threshold runs of about 4 miles, VO2max runs (3-4 x 1200m @ VO2max pace/ 400m walk-jog recovery), and lactate tolerance runs (10 x 400m starting on 2:00). The individual pace can be chosen from the Table in Figure 21.

During anaerobic threshold runs, the blood lactate concentration will average 3-6 mM and will be fairly constant. The heart rate will be around 85% of the heart rate reserve after 5-10 minutes and will climb toward maximal values after 45-60 minutes at anaerobic threshold. If the blood lactate falls after an early rise, or increases progressively during the run, the intensity of the run is, by definition, not at the anaerobic threshold. This intensity is probably one very good way to do a large volume of training. In addition to steady 4 mile runs, repeat 800m runs at this pace with a short (30 seconds) recovery can be done with a larger total volume of work accomplished. Idealized heart rate and blood lactate values for anaerobic threshold runs are presented in Figure 22a.

VO2max runs are essentially the same thing as tempo runs that are familiar to most coaches. Typical heart rate and blood lactate responses during VO2max runs are presented in Figure 22b. During these runs, the aerobic energy system is stressed maximally. They may also contribute to improved economy of running, although this isn't particularly important for speed skaters. The duration of VO2max runs should probably be less than 4.5-5 minutes. For slower runners, you may want to choose a shorter distance than the1200m recommended in Figure 21, but keep the pace the same.

During lactate tolerance runs, the heart rate will be close to maximal and blood lactate will be fairly high(~15 mM). This training session primarily challenges the glycogen degrading system and probably helps to build tolerance to muscle lactate. Because of its repetitive nature, it probably also stresses the aerobic system maximally. The key to this training session is the forced start on 2:00. For slower runners, the distance may need to be adjusted so that the relative work-rest relationship is similar to 90 seconds work/30 seconds rest. The first few repetitions may be quite easy, but the brevity of the rest period causes problems as the athlete continues. Heart rate and blood lactate responses during a typical lactate tolerance run are presented in Figure 22c.

Our basic recommendation for run training is to use each of the basic types of workouts, about 2x monthly . Aim for improvement in either the time, average pace or distance during each work out. We feel that a two mile time trial should be done about twice during the dry land period, late May and early August, to set the basic pace for each workout. The time trial is, itself, a pretty decent training session For example in a senior skater, an anaerobic threshold run might start at 2 miles and be increased by 1/2 mile each workout until 6-8 miles at anaerobic threshold pace is achieved. A VO2max session might be 2-3 x 1200m at VO2max pace, increased to 5-6 x 1200m. A lactate tolerance workout might start with 4 x 400m starting on 2:00. Each time the workout is done, add a repetition until 10 have been reached. .

CYCLING

Cycling, like running is a good way to do a lot of general conditioning in a fairly short period of time. Cycling has the advantage of using the same muscles as skating (hip and knee extensors), although there are differences in the forcefulness of hip and knee extension between cycling and skating and the absence of an isometric gliding phase in cycling. Depending on the pattern of pace, recovery, etc., the physiological responses during cycling can be highly variable. There probably is a place for the easy 30-90 minute ride in terms of general conditioning or recovery training. Beyond that the cycling training session chosen depends on the physiological adaptation desired.

Anaerobic threshold cycling sessions for the cornerstone of the cycling program. At the simplest level, continuous rides at a pace adequate to require about 85% of the heart rate reserve after 5 minutes of riding is pretty close to the anaerobic threshold. Most athletes will need to start at 10-15 minutes at this intensity. The duration should be increased as rapidly as tolerable up to about an hour. The same session can be accomplished on the cycle ergometer while riding at a constant power output. In the the example in Figure 23a, the athletes anaerobic threshold is about 200 Watts. This power output is sustained for about 20 minutes, with fairly constant blood lactate values.

Anaerobic threshold training sessions can also be fashioned out of interval training. For example, suppose that we want the muscular specificity of riding at 300 Watts, but want to be able to accomplish a large amount of total work (a merit of working at the anaerobic threshold). We might have the athlete do an interval training session at 300 Watts and 100 Watts with a 1:1 work:rest ratio (average power output=200 Watts). In Figure 23b we choose two minute intervals, that is two minutes at 300 Watts and two minutes at 100 Watts. We observe steadily increasing blood lactate values, indicating that we are above the anaerobic threshold. By decreasing the interval duration to one minute (Figure 23c), we achieve the metabolic response of working at the anaerobic threshold while enjoying the muscular benefit of being able to train at 300 Watts.

The example presented in Figure 23 suggests a very important aspect of interval training physiology. If the training session is too hard (above the anaerobic threshold), decrease the duration of the hard session. This is much more effective than increasing the duration of the recovery period. If a tempo or lactate tolerance type effort is desired, maintain or increase the duration of the hard session and lengthen the recovery session as needed to complete the session.

We do not have a good data for cycle training at VO2max in the field as we do for running. However, until we get the data, it would be reasonable to double the distances in the running chart in Figure 21. Instead of a 2 mile time trial, ride 4 miles all out. VO2max training then would be repeat 3200m rides at the same average pace held during the time trial, with about 2 minutes recovery between rides. On an ergometer, VO2max rides are easy if you have measured VO2max. Repeat rides of three to four minutes duration fulfill the criteria. In the absence of knowing VO2max, set the power output on the cycle ergometer at about 5 Watts/kg body weight for males or 4.3 Watts/kg for females.

In a similar fashion, lactate tolerance rides would be repeat 800m rides in about the same time suggested for 400m runs in Figure 21, with a new repetition starting every two minutes. Try to build up to 10 repetitions as rapidly as possible.

Another cycle training workout is the time trial. As part of the testing we have done with the National Team, we have measured responses during a 10 kilometer time trial (Figure 24). As can be seen, the pace is fairly constant, except for a "kick" during the last kilometer. Heart rate and blood lactate increase progressively throughout the ride. This training session becomes an VO2max training session. Because of the continuous nature of the ride, the total amount of work done is fairly small. Had we done repeat 2 kilometer rides at the same pace, we could potentially have done much more total work. At the same time, a time trial is a character builder. Its periodic use can help keep the athlete from looking for recovery at the end of the next interval. If you can arrange a time trial on an ergometer, it may also be very useful to you as a coach in that you can see (up close) how your athletes deal with fatigue. Some are stoics, some are fighters and some are whimps. Its hard to tell sometimes when they are passing you at 30 mph on the ice or you are trying to keep up with them on the cycle.

DRY SKATING

Dry skating is often used as a training activity, presumably to mimic the muscular action of skating. Monitoring endurance run/dry skate (4:00/6:00), we observed anaerobic threshold level blood lactate values, and heart rates about 20-30 beats/min below maximal (Figure 25). It appears that the slow tempo necessary to accomplish the technical goals of dry skating, keeps it in the range of anaerobic threshold type training. Data collected by the Dutch researcher Ruud deBoer have indicated that the VO2 during maximal dry skating is only 48 ml/kg in subjects whose VO2 during maximal ice skating is 62 ml/kg. This further suggests that its difficult to get really great cardiorespiratory provocation during dry skating.

LOW WALKS

Low walks are somewhat more physiologically challenging than dry skating. Data collected by deBoer indicates that low walking produces almost the same VO2 (60 ml/kg) as ice skating (62 ml/kg). Of course, the muscular similarity to ice skating is decreased by the use of a backwards leg thrust. It does, however, suggest that low walks might be a reasonable way to do physiologically challenging work in the down position during the summer.

FARTLEK

Many times, skating simulations are linked together with running in the form of a fartlek training session. Responses in three skaters during the fartlek session used by the National Team during the summer of 1988 are presented in Figure 26. Because of the length of this training session, the overall intensity was comparatively low, however the session did manage to achieve good heart rate and blood lactate responses, particularly during some repeat 300m runs done at about 140 minutes and during a terminal low walk session.

WOODER SQUATS

Alternating sets of one legged squats were developed by Dr. Mike Woods during the early 1980's as a way of getting a workout while finishing his medical residency. These have since been used by almost all of the National Team level skaters, particularly those under Wooder's coaching. Typically the athlete will start with 15-20 squats per leg per minute and alternate legs for 10-15 minutes. At the peak of training, an experienced skater might do 1 squat/second for 50 seconds, rest for ten seconds, then repeat the exercise with the other leg. This might go on for nearly an hour. The heart rate and VO2 response to this training session is fairly modest, however the blood lactate response is substantial suggesting that the muscular requirements might be very close to those of skating (Figure 27). Occasionally the skater will do continuous squats to failure as a test of his fitness. Wooder suggested that he felt that the ability to do 200 consecutive squats on each leg with good form and a 1/sec tempo was indicative of adequate competitive fitness. It's also good evidence that most of your brain has died. One variation of this technique is to rest one leg on a bench or chair to provide for balance and to add a barbell plate to your back to increase resistance. We feel that the dynamic balance required by doing the squats "free" has something to say for it. It might even be argued that adding the balance dimension of wearing skates while doing Wooder squats might be beneficial. The value of this has not been studied, however.

ROLLER SKATING

As already indicated, roller skating races produce about the same responses per time unit as do ice skating races. We have further studied blood lactate responses during training on roller skates. When elite skaters skate about 5000m on roller skates in about 15 min (a steady state kind of effort), the blood lactate responses are very similar to continuous ice skating of about 7500m

(Figure 28). The Dutch have used even longer roller skating efforts with good success in their all-arounders and distance specialists. Work by the Dutch physiologist deBoer has suggested very similar VO2 values during roller and ice skating. Interval roller skating 800m in about 2:00 (starting on 3:00), is somewhat harder than ice skating 1200m in the same time frame (Figure 28). Particularly with better and better roller skates becoming available, it seems hard to argue that speed skaters shouldn't do more roller skating than they do now. With the availability of roller skating races in the summer against the cross country skiers, we can't imagine why ice speed skaters wouldn't want to participate in some of these.

SLIDEBOARD

The slideboard is also used to mimic the muscular requirements of straightaway skating. During continuous slideboard exercise, blood lactate responses are very similar to continuous ice skating (Figure 28). Based on results from the Dutch, VO2 during maximal slideboard exercise is about the same as during skating. Our impression, however, is that when one tries to work at a fast tempo on the slideboard, skating mechanics deteriorate very quickly. It seems to us that, like dry skating, the slideboard might better be used to teach certain technical fundamentals and to secure anaerobic threshold intensity training. Trying to do VO2max or lactate tolerance training with this mode of exercise may cause so many technical problems that any physiological advantage is lost.

Beyond the immediate effect on the energy systems of the knee and hip extensors, it is important to remember that one of the important physiological functions of dry land techniques is to improve the skaters tolerance for the "down" position. Although the physiology of fatigue in the down position is hard to quantify, it certainly relates to lactate tolerance and lactate removal in the support muscles of the lower back and hip. Even if there were no effect of dry skating, low walks, slideboard, etc. beyond increasing tolerance of the down position, the time spent here would be worthwhile, particularly in the metric events where minimizing wind resistance and lengthening the stroke directly relate to being "down" and are critical to success.

ON ICE TRAINING

LAPS

During steady skating, what coaches call "laps", blood lactate is usually fairly constant at around 6 mM. If the pace increases even modestly, however, blood lactate can rise very rapidly. Heart rates are usually in the range of 85% of the heart rate reserve (Figure 29a).

INTERVALS

During interval training, such as 4 x 4 laps at 5000m pace, blood lactate is usually in the range of 9-11 mM (Fig 29b). Based on what we know about the pattern of lactate accumulation during competition (Figure 18), this seems to be an appropriate response. However, there is a great deal of muscular specificity for skating at different speeds. Thus, if you are preparing an athlete for a particular goal, say 8:00 for 5000m, its important to do lots of laps at around 38.4. seconds. As with cycling, it's important to remember that more total work can be performed by keeping the length of the hard segment fairly short, and the metabolic response near the anaerobic threshold. For example, doing 10 x 800 in 1:17 would be a much easier session than 5 x 1600 in 2:34, regardless of the rest interval. However, as the athlete is able to tolerate longer intervals at the target pace, the training session becomes more specific.

In preparing for shorter races, such as the 1500m, shorter intervals at a high pace are often indicted. These may have profound heart rate and blood lactate responses, particularly if the start is forced on a given time interval (Figure 29c)

Other training sessions, like step down intervals, often have blood lactate levels in the range of 6-10 mM and heart rates around 85% of the heart rate reserve. These sessions are sometimes more interesting than conventional intervals. However, it is harder to measure progress by watching the average lap decrease or the length of the interval increase.

One of our interests during the last couple of years as been to find the anaerobic threshold during interval skating. To do this we spent quite a bit of time doing "ice profiles". That is we measured heart rate and blood lactate after a series of 1000-1200m intervals, each a little faster than the last. We then followed heart rate and blood lactate during a training session of 10-12 constant speed 1000-1200m efforts. Our goal was to have elevated but unchanging blood lactates during the work out--to be at the anaerobic threshold. In figure 30 we depict an ice profile using 1200m repeats and a subsequent workout that satisfied the criteria for anaerobic threshold. Our feeling was that if we could define a heart rate at the anaerobic threshold for that athlete, then the athlete could work to maintain that heart rate later in the season, even if the speed necessary to achieve anaerobic threshold changed as the athlete became fitter. While the validity of this practice is undocumented, so far it seems to work fairly well. With the use of heart rate watches that several of the athletes have, its easy and accurate to track heart rate during an exercise session. We have assumed that a given heart rate should represent anaerobic threshold for a given athlete throughout the season. The Italian researcher Francesco Conconi, however, suggests that the heart rate associated with anaerobic threshold increases as the athlete gets fitter. Obviously, more work needs to be done here.

Because we found that repetitive blood sampling during ice profiles was limited by our ability to be present, we sought an easier method to identify the right speed for subsequent intervals. We had for some years been using a scale of perceived exertion developed by a Swede, Gunnar Borg (Figure 31). We then compared the rating of perceived exertion (RPE) during ice profiles (successively faster 1000-1200m efforts), to the rate of change in blood lactate during an interval workout of 1000-1200m repeats with a forced start every 3:00. We found that if the average pace during the intervals was about equal to the speed in the profile that led to an RPE of 3.9, the rate of change in blood lactate during the training session was near zero (Figure 32). This method clearly isn't as accurate as doing lactate profiles or determining the heart rate associated with anaerobic threshold, but its certainly less technology dependent.

Conconi has recently suggested a heart rate method for identifying anaerobic threshold that may be much simpler than blood lactate measurements and more accurate than perceived exertion. This is depicted schematically in Figure 33 for running and cycling-skating. As can be seen, the square of speed has to be plotted on the x-axis for cycling and speed skating since work for these two activities increases as a function of wind resistance, as the square of velocity. The test works well with the heart rate watches that are available to the athletes. For running, the speed should be increased every 200m. Starting at very slow speeds and increasing by even increments works best. It's probably best to have the coach pacing the runners on a bicycle (and recording the net elapsed time at the end of every 200m for later correlation with the heart rate data). Changing the speed by 0.5 mph per 200m is a convenient interval. For best results, the heart rate watches should be set in the 5 second memory mode. For cycling, the athlete can pace themselves as long as they have a speedometer on their bike. The elapsed time at the end of every 400m needs to be recorded for later correlation with the heart rates. For skating, a convenient distance is about 400m outdoors or 300m indoors. This will be a more difficult task to control, since external pacing is hard to provide on the ice (without leading the skater and changing aerodynamics) and since evenness of pacing is important for best results.

RESPONSES TO TRAINING

The purpose of training is to get better. The purpose of getting better is to skate faster. When skaters go through all the effort in training that they do, do they get better (faster)?

Many physiological characteristics are remarkably resistant to change in well trained athletes. VO2max whether measured running, cycling (Figure 34), or on the slideboard (Figure 35) changes very little throughout the duration of the dry land season.

Likewise, anaerobic power measured with the Wingate test doesn't change during dry land training (Figure 36). It fact, it often seems that many athletes get worse on the Wingate test if they have been particularly compliant with the dry land training program.

Do these findings mean that skaters don't get better with training? We believe that it's more a matter of the technology of evaluating physiological capacity than a failure of the training program. Athletes are already so physiologically adapted, that the changes that occur with training are subtle. For example, the day to day variability of many laboratory tests is on the order of 5%, or one-fourth of the change that takes place when sedentary people start training. However, it's probably two times the amount of change possible when a previously trained athlete increases his/her training.

Is it any wonder that its hard to measure changes in physiology in athletes?

Jos Geijsel, a scientist-coach from the Netherlands, found several years ago that the amount of time a skater could sustain a workload of 5 Watts/kg changes in response to the training load, even if the submaximal heart rate (an index of VO2max) doesn't change. The best performances on this ride seemed to be correlated with the momentary readiness of skate, at least in marathon skaters (Figure 37). Work that we did in 1987-1988 supports this concept. Skaters destined to be competitively successful the next winter, particularly in all-arounders improved more than skaters destined to be unsuccessful (Figure 38). We also found that 5 Watts/ kg was too heavy a workload for female skaters. They seem to get the same pattern of responses that males do at a workload of 4.3 Watts/kg. Improvement in this marker of endurance is fairly rapid in athletes spending time a training camps (Figure 39). Over the course of a summer, we have seen athletes change their endurance time from 5 minutes to over 20 minutes with regular cycle training.

Strength training is of clear importance to skaters, and is often an area of great training progress, as indicated earlier. However, to date we have very little hard data on changes in strength with training. Our observations suggest that in a multi-set squat workout, with enough weight to limit repetitions about 5, that the last three sets should be about 2.3-2.5 times body weight for elite skaters (particularly sprinters). We are cautious in recommending this as a goal, however, since squats done with improper technique can cause serious injury. Accordingly, until squat technique is very sound, trying very heavy weights is probably not a good idea.

Controlled laboratory studies of strength training are not plentiful. The available results suggest that training at the same time for strength and endurance interferes to some degree with strength gains, although it does not prevent them. Strength training does not interfere with endurance gains resulting from endurance training, an may even enhance them. Since speed skating is largely a muscular endurance sport, the combination of strength and endurance training favored by many coaches would seem to be sensible. If major strength gains are desired, this training should be undertaken at a time of the year when minimal endurance training is taking place.

Strength is somewhat velocity dependent. This is to say that strength gains at slow rates of limb movement don't necessarily transfer to fast rates of limb movement. Since the rate of limb movement in skating is fairly high (about 600 degrees/sec at the knee and hip joints), the logic of slow, heavy repetitions seems a little spurious, despite the evidence that heavy weights with squats is related to competitive success. From the standpoint of the available literature, the weighted jumps employed by many coaches would seem to make more sense for speed skaters. Likewise, since biomechanical evidence suggests that the first one third of the push off is the most meaningful, weighted jumps from a deep position would seem to make sense. On the other hand, strength in the deep position may allow the skater to maintain the static gliding position with a relatively easier contraction of the hip and thigh muscles. Since blood flow is reduced in muscles at greater than about 60% of the relative maximal contraction, being very strong may allow better blood flow and improve endurance even if it doesn't directly increase the forcefulness of the push.

Progress in skating is usually fairly hard to measure directly. Athletes eventually go faster than they have before, or their placings improve. But times and placings are highly variable outcomes depending on weather conditions, ice conditions and competition. During our early experience with the National Team, we performed repeat "profiles" on several skaters at West Allis in mid November and again in late December. Blood lactate increased progressively at faster skating speeds and better skaters had lower lactates at a given skating speed, as you might expect. Significantly, almost all of the skaters had to go faster in December to achieve the same blood lactate values (Figure 40). In scientific jargon, the curve had right shifted. This suggested to us that something about skating skill (effectiveness in the model presented at the start of this monograph) had improved.

To test whether we were seeing something happen, or just measuring the weather conditions, Nancy Swider-Peltz agreed to have several of the athletes under her guidance participate in an experiment where we studied the athletes on both the cycle ergometer and on ice in June and again in September. In this study the athletes skated on short track skates in a hockey rink. However, the pattern of skating was like metric skating--the skaters went by themselves against time. The velocity required to achieve a certain blood lactate concentration(10mM) (vLac) during 1500m profiles increased significantly, as did the maximal velocity (vMax) in a 1500m effort (they got faster) Figure 41. The improved skating speed occurred despite no change in the anaerobic threshold during cycling (OBLA) or in anaerobic muscular performance (AMP) on the cycle during the Wingate Test. These results suggested to us that these athletes were becoming more effective skaters by virtue of the on ice sessions that Nancy was giving them that summer. The results also suggested to us that maybe even metric style skaters should work on their technique on the ice in the summer. Despite the break that most skaters (and their coaches) seem to make with the short track once they begin to focus on metric events, this data suggests that important goals can be accomplished using this medium. Maybe skating on short track skates is more like metric skating than are some dry land exercises.

What generally should we expect as a response to training? In Figure 42 we present a generic model of the response to training, overtraining, and tapering. Generally the greater the training load, the higher the level of performance (A to B). In developmental skaters, the optimal training load will be less than the optimal training load eventually accomplished by that athlete. When training is then reduced (the athlete tapers), performance is further enhanced for a few weeks (B to C). The higher the training load prior to tapering, the better the response during the taper. Generally, it is fair to assume that most athletes will show progression of their training--they will be able to tolerate a greater load this year than last year.

When training becomes very intense and very prolonged, two negative responses can occur. The first of these is overreaching, where the athletes performance deteriorates (B to D). However, if the training load is decreased the athlete recovers fairly promptly (D to E). Some coaches will deliberately push athletes into the overreaching area and then back off to ensure maximal rates of adaptation. This is a coaching technique that is very valuable if conducted carefully by an experienced coach with a good understanding of that particular athlete. However, for some athletes, when overreaching is carried on too long, the overtraining syndrome develops (D to F). This means that performance deteriorates and doesn't recover when the work load is decreased (F to G). It is a season ender. Overtraining is particularly sneaky in that it is very individual dependent. Deliberate overreaching that works for one athlete may cause overtraining in another athlete working with the same coach. It also takes advantage of the personality of coaches and athletes. How do coaches and athletes respond to deteriorating performances? Do they back off and let adaptation occur? Of course not. They work harder, the athlete must be out of shape. For every athlete that is out of shape from working hard, we can name about 10 billion that are just tired and need a break before working hard again.

There are several things we know about overtraining, however, that make the problem preventable, even if we don't fully understand it's physiology. Overtraining is related to the relative training load. Reasonable training loads for an elite skater are likely to be too much for a developmental skater. Every athlete has his/her own threshold for overtraining. Even some elite skaters are always susceptible to becoming overtrained, whereas others thrive on hard work. The presence or absence of rest and recovery days is probably more important to the development of overtraining as is the severity of any one (or ten) training session(s). Thus, skaters tend to become overtrained when the workload is greater than usual for an extended period of time, <u>and when rest days are eliminated</u>. The presence of competition increases the likelihood of overtraining, mainly by increasing the intensity of training. It is also important to remember that overtraining is part of a general stress syndrome. As such, other stressors in the athletes life may modify the effect of a given training load. Thus, a training load handled easily when the athlete is happy, well rested, and not highly involved in other activities may be too much when the athlete is in school, working a part time job, or fussing with their current romantic involvement. Travel, particularly international travel, is a particularly great stressor and can predispose the athlete to overtraining.

Its safe to assume that as long as the athlete is making definite progress, overtraining isn't happening. If the athlete is better this week than last week and if they respond with enthusiasm once the workout starts, even if they complain between workouts then you can forget worrying about overtraining.

When performance in either training or competition falters, your job as coach is to ask if the athlete is inadequately prepared or perhaps is reaching their current capacity to adapt to training. In very highly motivated individuals, like athletes, inadequate preparation is the less likely of the two possibilities. It may well be that a day away from the sport is going to do more good than an extra workout. As an example, we attempted to experimentally overtrain several skaters during a camp in Marquette, MI during the summer of 1988 (Figure 43). After a few days of accommodation, coach Mike Crowe instituted what he perceived to be a very hard training program for 3 1/2 weeks. The skaters performed endurance rides on the cycle ergometer on a weekly basis throughout the time period. For the first two weeks, the skaters responded very well to the program. They claimed to be getting tired, but their performances continued to improve. During the next 10 days, performance flattened and even deteriorated in some skaters. They were at least overreached. Were they overtrained? Three days of rest led to significant performance improvements in every skater, with every skater recording an all time best performance. Since they recovered they were, by definition, not overtrained. We believe that if the experiment had continued longer we might have achieved overtraining. Significantly, however, every skater found a way to take a day or two off during the heavy training period. They were motivated, but this wasn't an Olympic year and the group was largely junior skaters more interested in technical development than in getting in super shape.

World Team member Chris Shelly, between grousing about the "over testing camp" put his finger on the nugget of the problem when he observed that the previous summer at a month long camp in Colorado Springs (where we saw some evidence of overtraining) "all the big boys were there and every workout was a race". He further observed that "no one would take a day off, you might get behind".

In the Marquette group, the threshold for overreaching seemed to be two weeks of heavier than usual training (with some rest days stolen despite our best effort). Even another 10 days didn't produce full blown overtraining, but we think that it was close. Our belief is that for younger skaters (juniors) at least a day per week of no training at all is a good guideline, and for intermediates and down the need for rest may increase. For senior skaters, 10 days to 2 weeks probably represents the longest a heavy workload can be sustained without a day off. We feel that over-training develops when you as coach feel that you have to sacrifice a scheduled day off to work on some specific goal-"just this once", or when travel, competition and jet lag catch up with a scheduled day off.

EVALUATION OF SKATERS

One of the more visible roles of sport science is to help coaches evaluate athletes. This often involves some sort of laboratory test to "evaluate" the athlete and either to define progress or identify talent. In many cases this process is disappointing because, as we have seen, many of the laboratory measures that are popular with sports scientists are remarkably resistant to change with training. Thus, in many programs, systematic evaluation of athletes is a very on-again-off again proposition with the result that little good is accomplished. In speed skating we have been fortunate that during the last 7-8 years the National Team coaches, first Dianne Holum then Mike Crowe, have been very interested in systematic evaluation and, more importantly, very patient with slow short term progress. This patience has been mirrored by both Susan Sandvig and Nancy Swider-Peltz, and has allowed us to accomplish much more than sports science groups in other sports. As a result, we have finally come to the point where we feel that we can begin to do some good for the skater and their coaches by using contemporary sports science technology.

For a laboratory test to be useful it must fulfil at least two criteria. It must have some correlation with performance and it must reflect reasonable progress with training. As a secondary consideration it should be amenable to goal setting. In sports like running, cycling, swimming, etc. it's easy to have a periodic time trial to measure progress. In speed skating periodic assessment is hard because of the lack of venue availability in the summer months and the lack of standardized conditions during the winter. Even in indoor arenas, ice conditions can change drastically in very short time periods and make time trials hard to interpret.

Our first studies with the speed skating team in 1979 used treadmill running to measure VO2max. Outside of determining that skaters selected for the Olympic Team had slightly higher VO2max's than non Olympians and that 1979 skaters had higher VO2max's than 1967 skaters, the results failed to meet either criteria for a useful laboratory test. The skaters actually had slightly lower VO2max's in December than they had in May. Of course the December tests were the morning after the post Olympic Trials party (would that influence results?). Subsequent studies of VO2max on the cycle ergometer, revealed that there was a reasonable relationship between VO2max and later skating performance (best

1500m time the subsequent winter)(Figure 44), but that there was no net improvement across the dry land season (Figure 34). The next year we determined that 1500m skating performance was also well related to VO2max measured on the slideboard (Figure 45) but, again, there was no net change in VO2max over the dry land season (Figure 35).

Spurred by reports from Dutch researchers of correlations between anaerobic performance on the cycle ergometer and skating performance, we spent three years testing skaters on the Wingate Test. The Wingate Test involves sprinting as hard as possible for 30 seconds on a cycle ergometer with the ergometer set in a very "big gear". We found, in agreement with the Dutch, that there was an excellent correlation between the results of the Wingate Test and skating performance (Figure 46). Again there was no net change across the skating year (Figure 36).

The lack of change in these tests was very disappointing, particularly in that the skaters were beginning to get used to us and to look to us for feedback. Its very hard to tell an athlete who has just finished 4 months of very hard training that he got worse. The lack of any common sense meaning to these results suggested to us that something was wrong with the tests, and that something new had to be tried.

Again spurred by a Dutch report that the duration a skater could keep pedaling the cycle ergometer at a power output of 5 Watts/kg (endurance time) was related to marathon skating performance (Figure 37), we began studies using the endurance time test. We found that 5 W/kg endurance time was well related to subsequent 1500m performance (Figure 47) and that, in male skaters, there was improvement across the dry land season (Figure 48). The test even seemed able to discriminate between competitively successful and competitively unsuccessful skaters (Figure 38). With female skaters the test seemed to do a much poorer job of tracking performance (Figure 49). When we analyzed the relative work load represented by 5 Watts/kg, we began to believe that 5 Watts/kg was too hard for female skaters. Riding a 5 Watts/kg requires a VO2 of about 65 ml/kg. This represents about 105% of the average VO2max in American male skaters. As such, an average time of about 6 minutes might be expected. For the average American female skater, 65 ml/kg represents about 125% of the average VO2max. Even with improvement, the very high intensity of the test just did not allow for measurable improvement. When we adjusted the work load for the average VO2max in female skaters, to 4.3 Watts/kg, endurance time was related to performance (Figure 50). and the endurance time improved with training (Figure 51). Skating performance appears to improve out through endurance times of about 16 minutes, suggesting that about 15 minutes represents the limits of basic fitness for skaters (Figure 52).

As an added advantage, the endurance time test appears amenable to goal setting. Based on our experience, there are very few senior skaters who will be competitive at the national level with endurance times much less than 10 minutes. On the international level, about 15 minutes seems to be the lower limit of competitiveness. This fits the endurance time -1500m performance data in figures 50 and 52. Achieving these goals does not guarantee success. Failure to achieve these goals during the summer leaves questions regarding the basic fitness of the skater. A few pure sprinters may not be necessarily hampered by lack of enough fitness to achieve goal performances, although it wouldn't hurt most skaters to err on the side of being too fit. For junior skaters and younger, short track specialists, and pack style skaters we doubt that the absolute need for endurance is as great as in metric events. From the Dutch results with marathon skaters around 10 minutes seems to be a lower limit of basic fitness. Very limited results that we obtained in 1987-1988 suggest that about 7 minutes seems to be the lower limit for candidates for the Junior World team, with the pure sprinters again seeming to "beat the system".

Murphy's law works for sports scientists just as often as it does for every one else. As soon as we came up with a useful way to evaluate speed skaters, we were presented with another problem. The method of evaluating skaters that we had developed worked very well in our lab in Milwaukee. The National Team was in Calgary. Carrying a 200 pound cycle ergometer through the Calgary airport wasn't our idea of fun. We came up with an interesting solution. We found that a device that cyclists use to train indoors, the Road Machine, could be calibrated, in terms of speed equivalents, to the Watts used with a cycle ergometer. However, because the workload was not automatically maintained by the bike (in addition to being heavy, our cycle ergometer is smart), we couldn't use endurance time in the same way we had been using it. It would be too easy to slow down for a few seconds, get a rest, and go on, forever. However, if Watts were equivalent to speed and speed over time is distance, we felt that we could compute time goals to ride certain distances. By making a couple of assumptions we came up with individual time goals for a 10 km time trial based on sex and body weight (Figure 53). We had skaters perform the time trial and obtained results that seem very reasonable in terms of the physiological responses during the ride (Figure 24). We have yet to be able to correlate the 10 km time trial with endurance time, to compare time trial performance to skating performance the subsequent winter, or to see if the time trial tracks progress. These are goals for the future, but we are optimistic. If a 10 km time trial works on a road machine, it should work on other types of ergometers that are available to athletes, like the Velodyne made by Schwinn. The time trial concept might even work on a real bike on the road. Could it be that we have put ourselves out of business? Accordingly, the chart in Figure 53 is presented as our tentative idea of a cycling fitness test for skaters. Basically the heavier, the faster the skater should be able to ride. At the same weight, males should be faster than females. Thus, a 200 lb male would need to be able to average 26.2 mph to achieve his goal (14:10), and a 125 lb female would have a goal of 16:45 (22.2 mph). Our suspicion is that juniors might need a shorter time trial with the same average speeds, but that's something we'll learn in the future, if the coaches continue to be patient with us. These times are also comparatively slow for really good cyclists. It suggests that the endurance time/time trial represents an element of basic fitness for speed skaters. Once this minimal level of fitness is achieved, the skater should probably spend their effort more profitably working on more skating specific training and with only maintenance effort going into cycling.

NUTRITIONAL SUPPORT

Cars don't run without fuel. So too, athletes aren't very fast without fuel, or with the wrong kind of fuel. Although the principles of sports nutrition are really no different than the principles of ordinary nutrition, and although there is a lot of hucksterism in sports nutrition, there is still much to be gained from the intelligent application of a couple of simple techniques.

For exercise to proceed at high intensity, carbohydrate is an absolutely required fuel. Although low intensity exercise can be sustained for very long periods of time from the bodies stores of fat (there are enough calories in the 11.2 lbs of fat (160 lbs x 7%) of the average male skater to walk 500 miles or presuming that you can skate 15 miles at an easy pace in an hour, to skate 2100 miles, or Minneapolis to Dallas and back).

If there isn't the right kind of fuel (carbohydrate) immediately available to the muscle (in the form of muscle glycogen) about all you can do is walk. This may be fine for getting from point A to point B, but winning gold medals is about going fast. As indicated earlier, muscle glycogen is used very rapidly during skating, particularly skating at high intensity (Figure 14).

Abnormal diet for an American teenager contains about 45-50% of the calories as carbohydrate or about 250 grams of carbohydrate daily. This isn't an enough carbohydrate to restore muscle glycogen following heavy training or competition. This leaves three options; 1) the athlete can continue to train or race, and become progressively more muscle glycogen depleted, 2) they can take an extra day or two between workouts/races, but its hard to improve while training only 2-3 days/week, or 3) they can find ways to increase their carbohydrate intake. It's well established that athletes can sustain day after day of high intensity exercise without progressive muscle glycogen depletion, if the carbohydrate intake is very high (Figure 54). One method is by eating more food, with the same percentage carbohydrate composition. More carbohydrates are obtained, muscle glycogen is restored; but Porky the Pig doesn't skate very fast. Another method is by changing the percentage composition of the diet to a higher percentage of carbohydrates. This allows the caloric intake to be well regulated, but gives the athlete what their body needs.

The idea is simple. The execution is not. In the United States, and particularly among the young who eat more "fast" food than others, its very difficult to eat what amounts to a "strange" diet needed to get about 70% of calories from carbohydrate. We worked with the National Team on this problem for a couple of years, after it became obvious that the skaters in the late 70's-early 80's were chronically glycogen depleted, to teach the athletes how to make good food choices. Even after they had the knowledge, they couldn't execute the diet.

During this same period of time, we had also been working with Ross Laboratories on the development of a glucose polymer beverage. Glucose polymers (maltodextrins) represent a midpoint between starch and glucose. As such they are easier to empty from the stomach than glucose, easier to digest than starch, easy to consume (they are usually formulated as drinks), and not a sweet as glucose or sucrose based drinks (this is probably the biggest single argument in favor of glucose polymers). We found that consuming glucose polymer based drinks led to faster restoration of muscle glycogen. Subsequent studies led to the observation that very heavy exercise could be sustained longer and more lactate could be accumulated after exercise when athletes were taking a glucose polymer based supplement after training sessions (Figure 55). Thus we felt that we had found a way to increase the skaters carbohydrate intake by giving them what they most wanted (fluids) right after training. About this time we entered a period where Ross Laboratories, makers of EXCEED Nutritional Products, sponsored the National Team through 1988. We found that using EXCEED High Carbohydrate Source was a convenient option for the National Team. We did find that there was a considerable incidence of gastrointestinal complaints if the beverage was mixed at 23% carbohydrate (23 gm of carbohydrate in 100 ml of fluid) per company directions. However, when the concentration of the drink was decreased to about 17% carbohydrate (adding 5 cups of water instead of 3 per bag of powder), the skaters seemed to derive the benefits of the supplement without the side effects.

Sometime later, after the skaters were well used to the supplement, we became concerned that some of the skaters might be using so much of the supplement, that their intake of other nutrients might suffer. In dietary surveys, however, we found that, with the exception of iron, most of the nutrients were well represented in the regular food consumed by the athletes. For this reason, we believe that with or without glucose polymer use the skaters should take a one a day type vitamin with iron. Since iron is absorbed much better in the presence of food (particularly red meat), the vitamin/iron supplement should be taken with meals.

Research in Sweden has demonstrated that with a high carbohydrate feeding immediately after exercise, considerable muscle glycogen can be restored in the space of 2-4 hours (the interval between races) (Figure 56). Subsequent research at the University of Texas (Figure 57) has demonstrated that the muscle is particularly willing to restore muscle glycogen when carbohydrate is consumed <u>immediately</u> following exercise, as contrasted to 2 hours later. Therefore, in the 1987-1988 Winter we had the skaters take their bottle of EXCEED on to the ice with them and consume it during their warm down. In situations of multiple races during a day, there is occasionally some fullness of the stomach at the start of the next race, but we don't seem to have any problem with nausea or throwing up during the second race. There are also suggestions, from research at the University of Iowa, that athletes may become much better at emptying fluid from the stomach with repeated practice. Thus, if you plan to use this feeding strategy above, make sure your athletes do it in practice.

Early studies in our laboratory indicated that significant feeding 30-45 minutes prior to exercise might have a deleterious effect, particularly in more prolonged (30-60 minute) events (Figure 58). The insulin response that follows carbohydrate feeding tends to lead to hypoglycemia (lowered blood sugar) and increases in the rate of muscle glycogen use if hereby exercise starts at the peak of the insulin response. Although this apparently doesn't hinder performance in shorter events, it may lead to hypoglycemia right after exercise. The simple solution is not to eat for about two hours prior to the first event or prior to the workout.

Carbohydrate feeding can significantly delay fatigue during very prolonged exercise, such as training sessions. Research at the University of Texas has shown that frequent carbohydrate feedings, prior to the development of fatigue, may allow a significant prolongation of high intensity exercise from about 3 hours without feeding to about 4 hours Figure 59). This seems to happen regardless of the status of muscle glycogen stores. Thus during prolonged exercise bouts, we recommend feeding during exercise or during breaks if you are interested in intensity at the end of the training session.

For some athletes, getting enough food in during the day is difficult. Training-school-work-etc. make eating a problem. Obviously ordinary food is the best solution. However, failing that there is a nutritional supplement that provides a reasonably balanced intake in an easy to take form. This is EXCEED Complete Liquid Nutritional. It is a milkshake like product, modified from ENSURE Plus, a nutritional designed for nursing mothers. It shares some characteristics that Crocodile Dundee ascribed to certain Australian roots. Seriously, about 50% of people don't much like the taste of the Nutritional Beverage, but if you need calories in a reasonably nourishing and portable format, its worth a try.

Many of the foregoing recommendations depend on the use of nutritional supplements. They work well, but they are expensive. Although not as convenient or as likely to be adopted by 16 year olds, there are a few things that can be done to enhance carbohydrate intake using real food. They are surprisingly simple. The first is fruit. Usually the carbohydrate content of most fruits is fairly high. A snack of apples, grapes, raisins etc. between races or right after workouts can make a step in the right direction toward restoring muscle glycogen. Bread, crackers and cereals particularly the whole grain varieties are fairly carbohydrate rich. Washed down with water, they are fairly easy to take to the training site and can be useful. The trick is to consume them right after the exercise bout is over. Even if weight control is something of a concern, we would rather see athletes chowing down right after the workout with something carbohydrate rich than waiting two hours and chowing on pizza. As an added benefit, eating right after the exercise bout may suppress the appetite later and lead to more controlled intakes of the things that the skaters are probably going to eat anyway even if they aren't so good--pizza, burgers, fries etc..

Beyond the need for eating as soon after the exercise bout as possible, the most important meal for athletes, as for everyone else, is probably breakfast. This meal seems to set the tone for the rest of the day, and may be particularly important for athletes attempting to lose weight. There are several cereals that are low fat and high in iron that, together with skim milk, juice and fruit, for the nucleus of the days diet. These cereals are 40% Bran Flakes, Corn Flakes, Fruit and Fibre, Fruitful Bran, Product 19, Raisin Bran, Total, and (inevitably) Wheaties.

Beyond this, nutrition is mostly common sense. There may be a little sacrifice involved in arranging for good meals instead of junk food, but why sacrifice the time and effort to train, travel and compete, not to mention the expense, if an athlete is going to hurt themselves by being either carbohydrate depleted or too fat.

CONCLUSIONS

Hopefully, you know a little more about the physiology of speed skating than you did before we started. We've tried to be as non technical as possible, but that's sometimes hard to do and still explain what is happening to the skater. If there are points you don't understand, please feel free to call. We are more than willing to talk about specific issues.

As a parting thought, it might be worthwhile to discuss where sports science fits into the basic scheme of preparing athletes for competition. We feel that there are basically three areas where we might be able to help, although the ways we can help may be different than the popular media would have your believe.

1) The Laboratory of Mr Goodwrench: The popular version of sports science is that you can bring your athlete to your friendly local scientist, plug him or her in to the technology and determine whether the athlete is ready to skate 38.5 or 38.6 for 500m. As we have seen, although we know a good deal about the physiology of skating and are beginning to get a handle on how to evaluate skaters, we are light years from this fantasy. Our biggest problem is the longitudinal response, is the athlete improving? It has taken us nearly a decade of work with the coaches and skaters to begin to solve this problem. Also, most of our evaluation techniques are so coarse (5% day to day variability is considered normal), that we can't distinguish the 1% difference in performance that separates the winners from the "also rans".

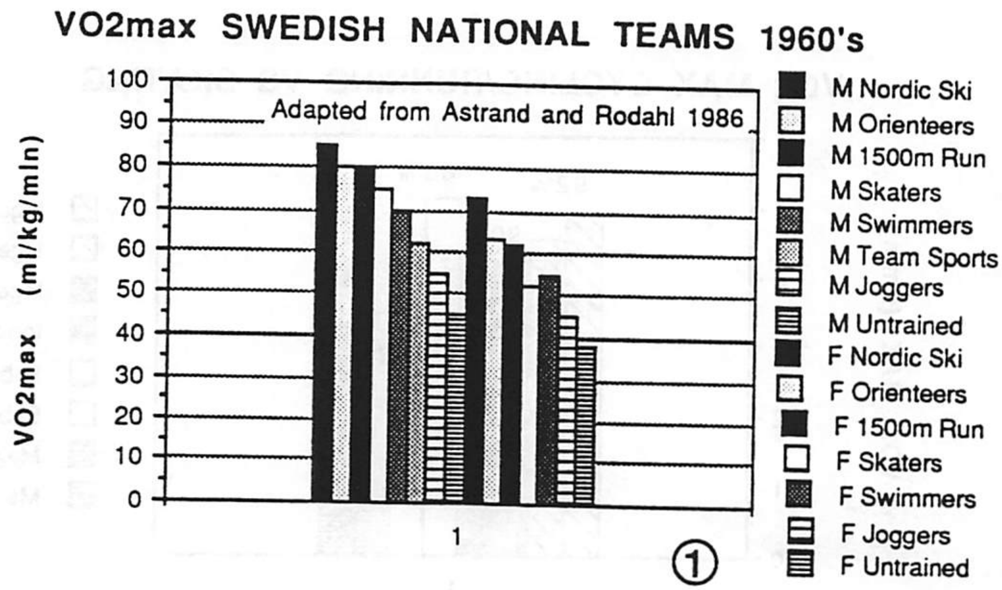
2) X-Ray Glasses for the Coach: One of the areas in which we seem to have been most successful in the past few years is in providing the coach with a different perspective in which to view skaters. Just as your video tape machine can improve your "eye" for technique, the use of contemporary technology--heart rate monitors, lactate analyzers, etc.-- can let you see how your athletes respond to specific training sessions.

3) Shortening the Technology Gap: Another area in which we have been very successful is in decreasing the time required to get information from the laboratory and scientific journals to the coaches. Consider the gap between the first studies of "carbohydrate loading" in marathon runners in the early 1960's to its first use in

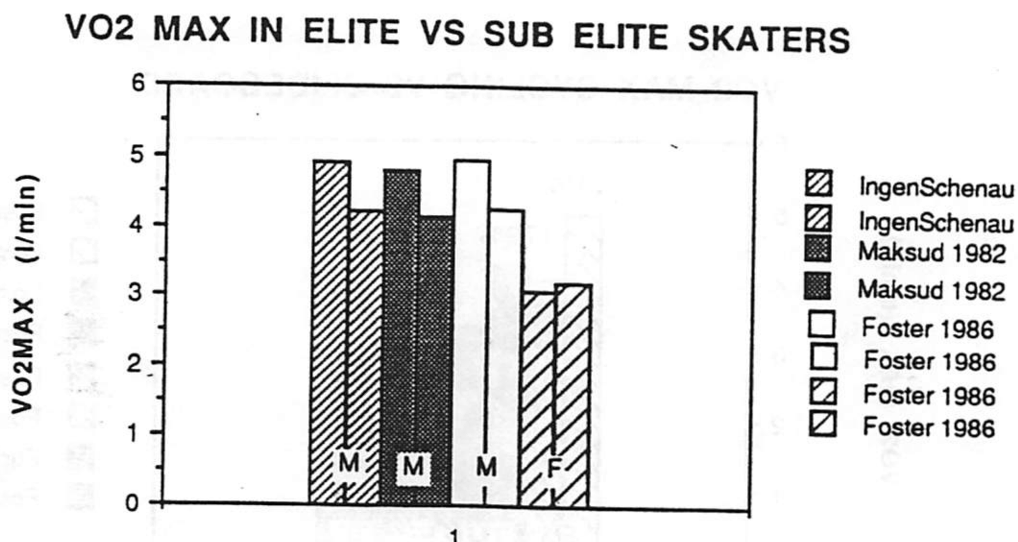
competition in 1970, a 7 to 8 year technology gap. We were able to use the information indicating that muscle glycogen replenishment is best immediately after exercise even before it was published, thanks to our links in the scientific community and with National Team Coach Mike Crowe. Hopefully, this monograph takes another step in reducing the technology gap by reaching broader than the elite coaches.

In the last analysis, sports science is a tool for you to use. It will not make a slug into a champion, but awareness of the principles of physiology might make a 1% difference in performance. For a 2:00 1500m performer, 1% is 1:58.65. In the competitive arena, that's a lot of difference. Whether we are ever able to work with you as individual coaches, time will tell. If we do, think of us as your assistant coaches. Your assistant coaches do limited things to help you in your overall job of helping skaters go faster. We aren't magicians, but we do some limited things quite well. In the interim, if you have questions feel free to call Carl or Nancy at (414) 283 6751 or Ann at (414) 229 6065.

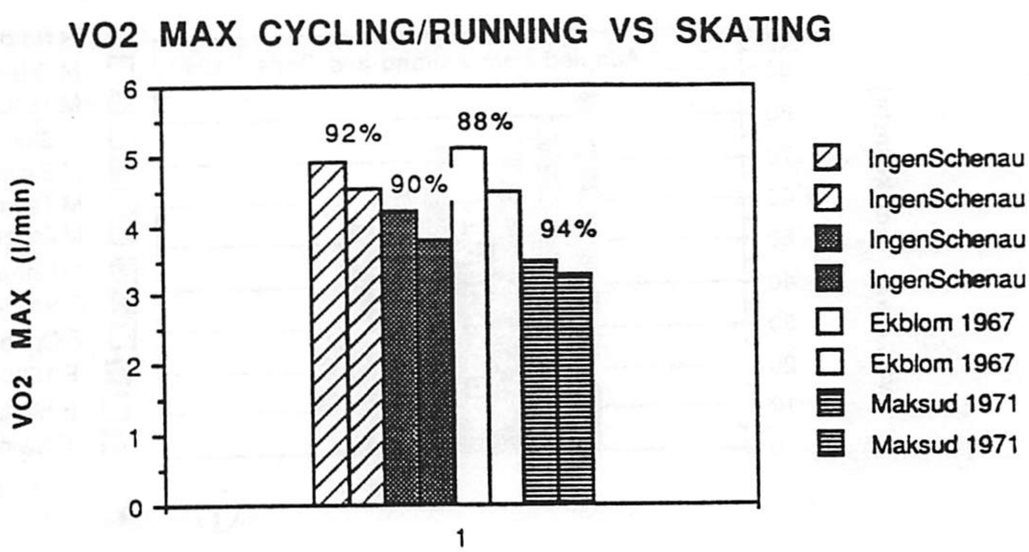
FIGURES

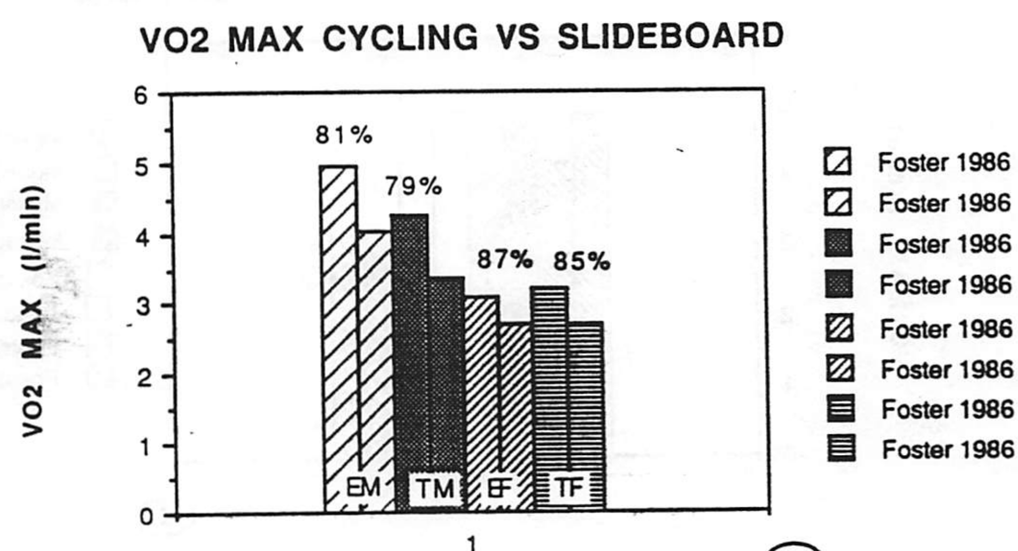

VO2max SWEDISH NATIONAL TEAMS 1960's
Adapted from Astrand and Rodahl 1986
VO2max (ml/kg/min)
100
90
80
70
60
50
40
30
20
10
0
1
M Nordic Ski
M Orienteers
M 1500m Run
M Skaters
M Swimmers
M Team Sports
M Joggers
M Untrained
F Nordic Ski
F Orienteers
F 1500m Run
F Skaters
F Swimmers
F Joggers
F Untrained

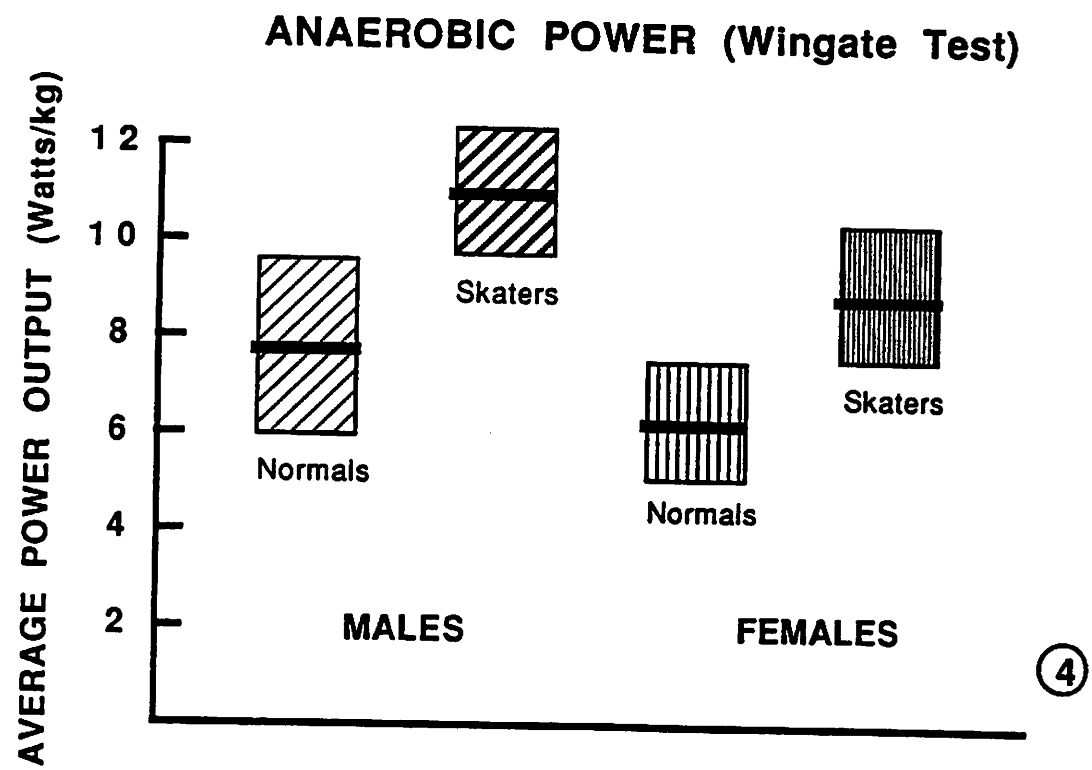
1

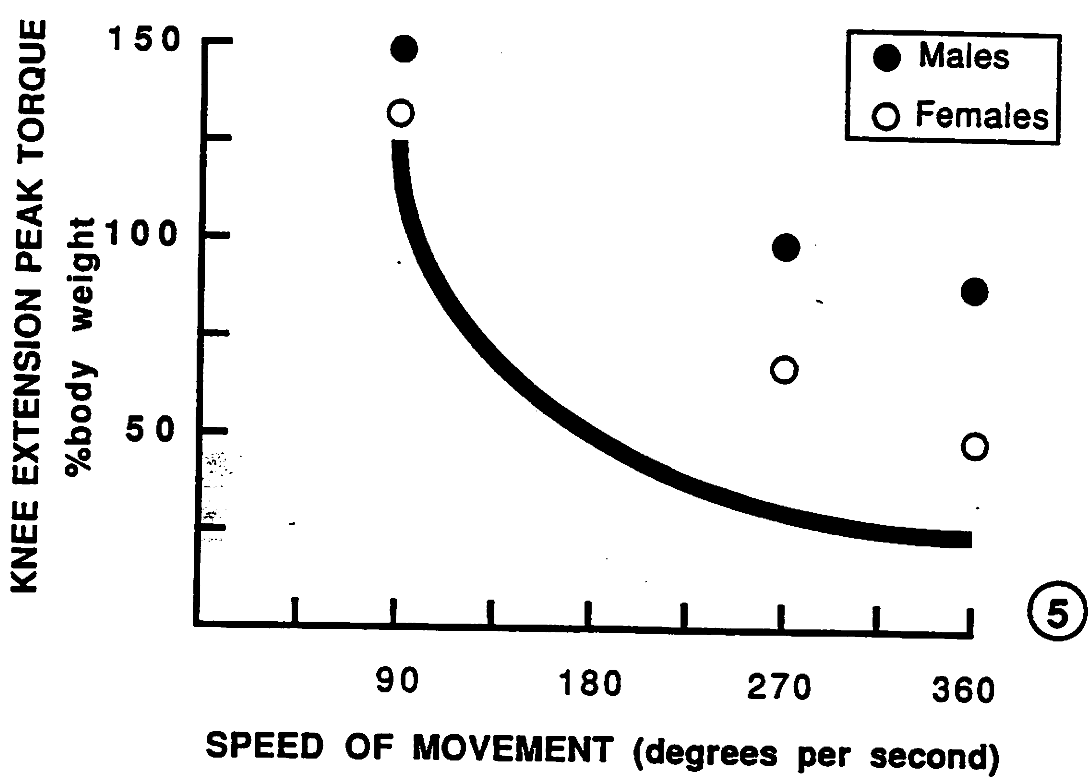

VO2 MAX IN ELITE VS SUB ELITE SKATERS
VO2MAX (l/min)
6
5
4
3
2
1
0
M
M
M
F
1
IngenSchenau
IngenSchenau
Maksud 1982
Maksud 1982
Foster 1986
Foster 1986
Foster 1986
Foster 1986

2

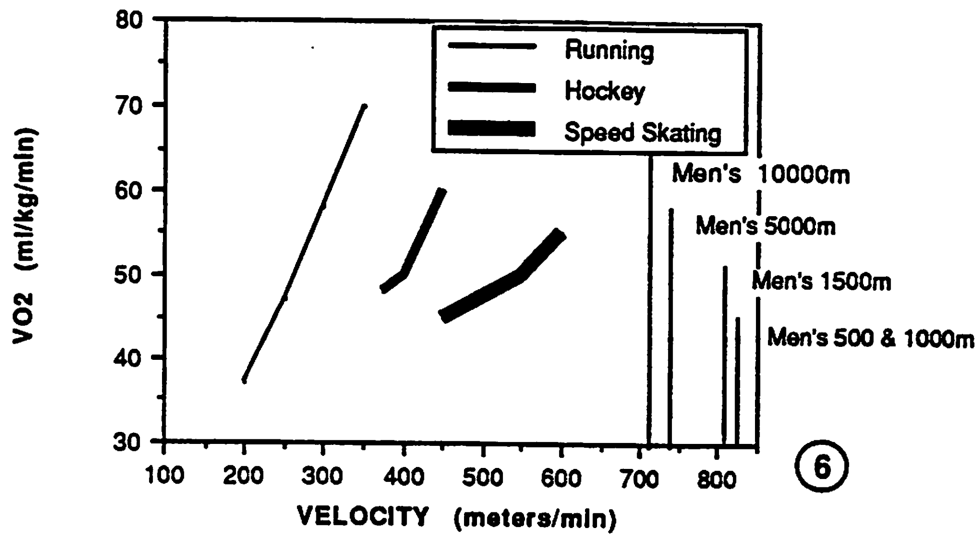

VO2 MAX CYCLING/RUNNING VS SKATING
VO2 MAX (l/min)
0
1
2
3
4
5
6
92%
90%
88%
94%
1
IngenSchenau
IngenSchenau
IngenSchenau
IngenSchenau
Ekblom 1967
Ekblom 1967
Maksud 1971
Maksud 1971


VO2 MAX CYCLING VS SLIDEBOARD
VO2 MAX (l/min)
0
1
2
3
4
5
6
81%
79%
87%
85%
EM
TM
EF
TF
1
Foster 1986
Foster 1986
Foster 1986
Foster 1986
Foster 1986
Foster 1986
Foster 1986
Foster 1986


ANAEROBIC POWER (Wingate Test)
AVERAGE POWER OUTPUT (Watts/kg)
12
10
8
6
4
2
Skaters
Normals
Skaters
Normals
MALES
FEMALES
4


KNEE EXTENSION PEAK TORQUE
%body weight
150
100
50
Males
Females
90
180
270
360
SPEED OF MOVEMENT (degrees per second)
5

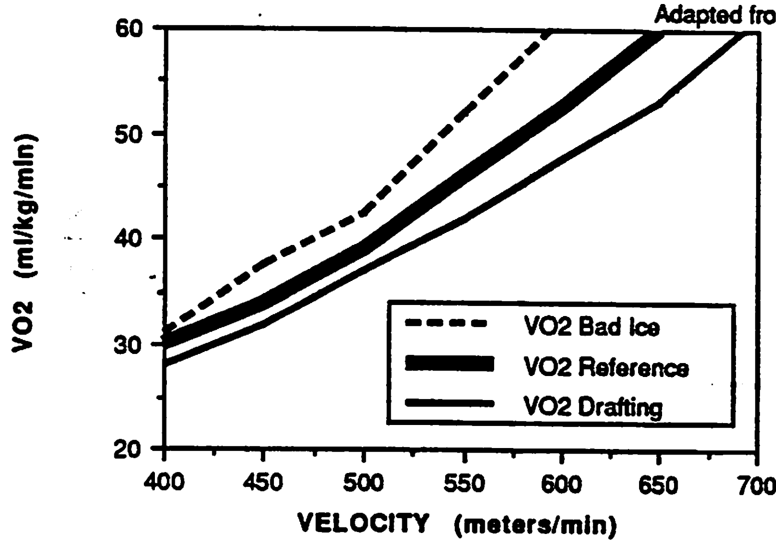
AEROBIC DEMANDS OF RUNNING AND SKATING



6

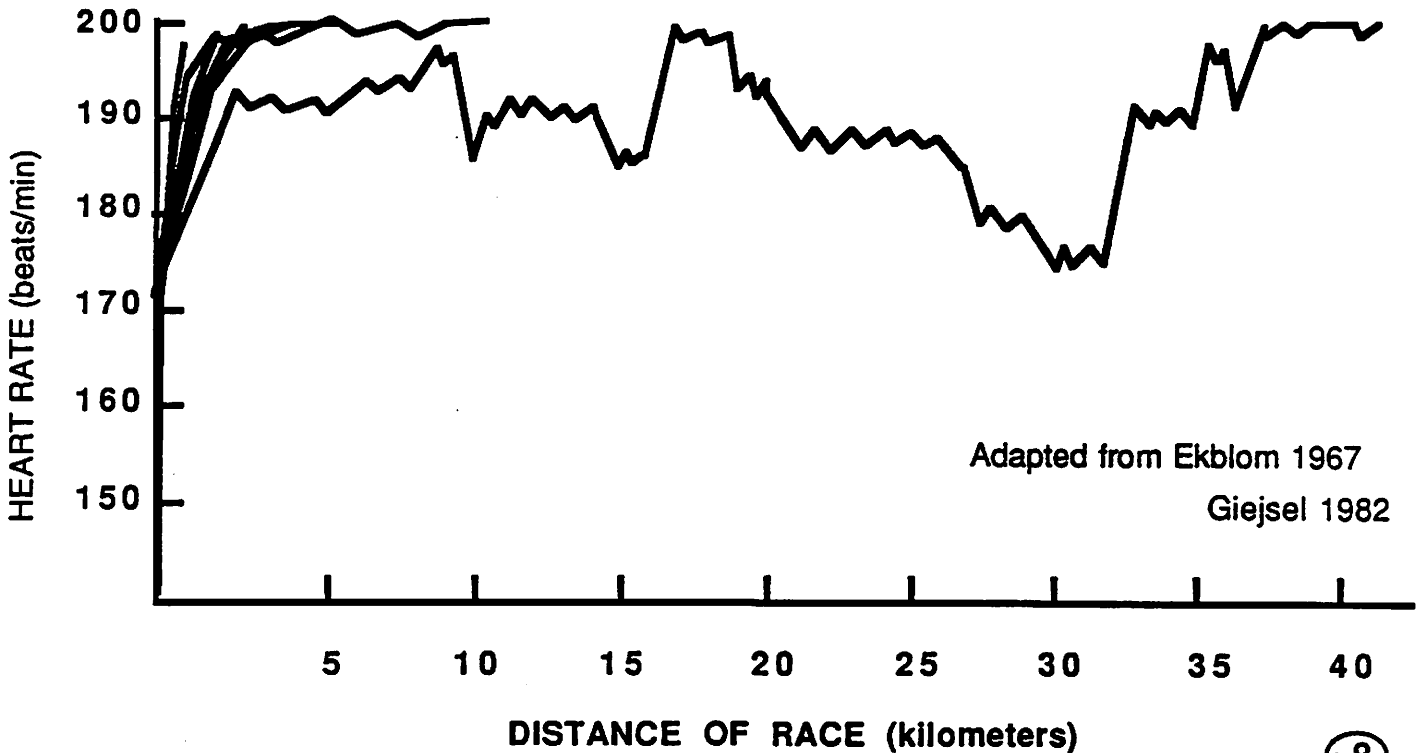
OXYGEN UPTAKE WITH DIFFERENT CONDITIONS

Adapted from Ekblom



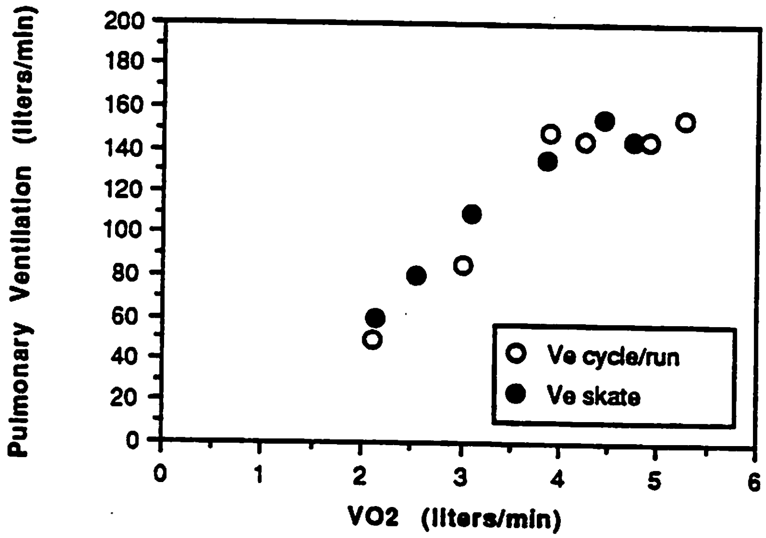
7

HEART RATE RESPONSE DURING SPEED SKATING



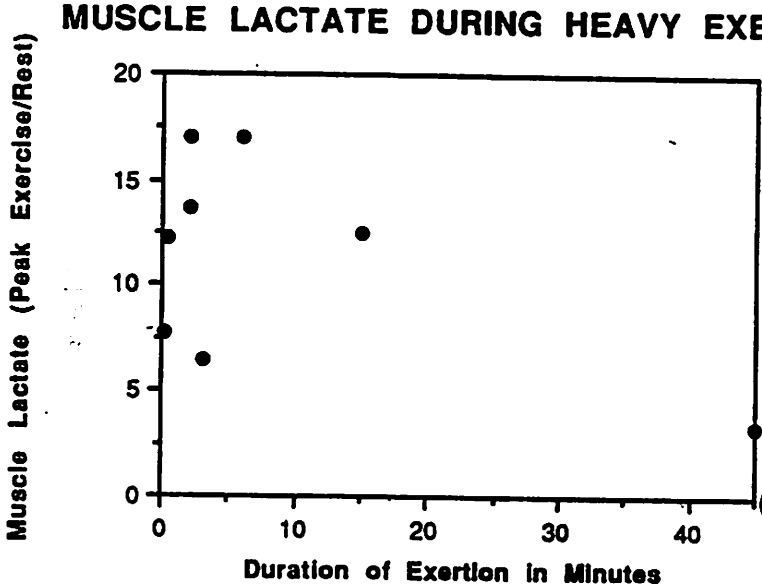
8

VENTILATION VS VO2 IN SKATERS



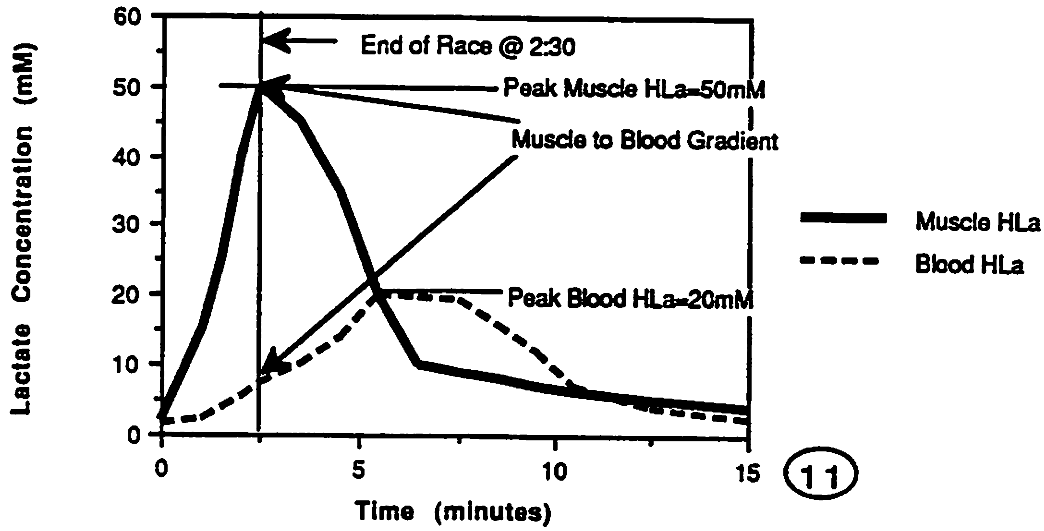
9

MUSCLE LACTATE DURING HEAVY EXERCISE



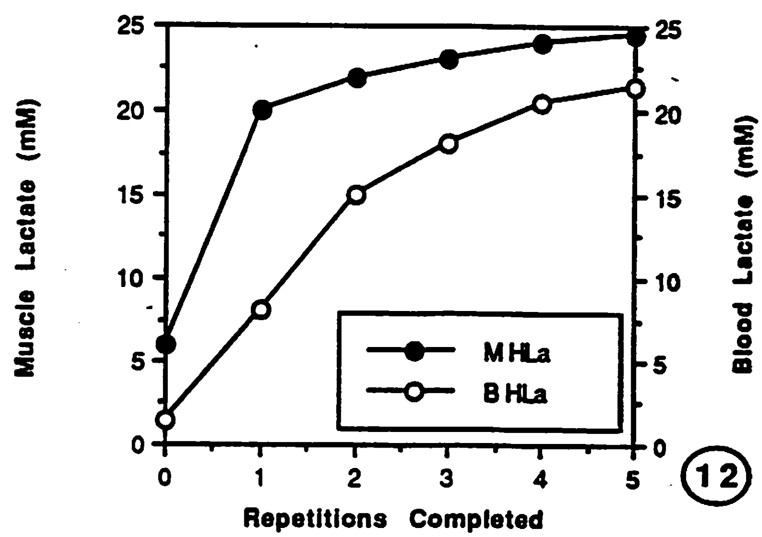
10

MUSCLE & BLOOD LACTATE DURING A RACE



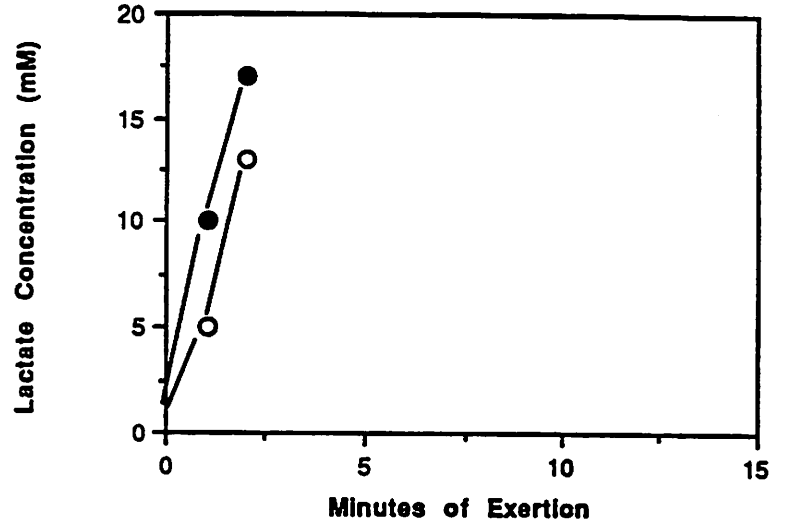
11

MUSCLE AND BLOOD LACTATE IN REPEAT EFFORT

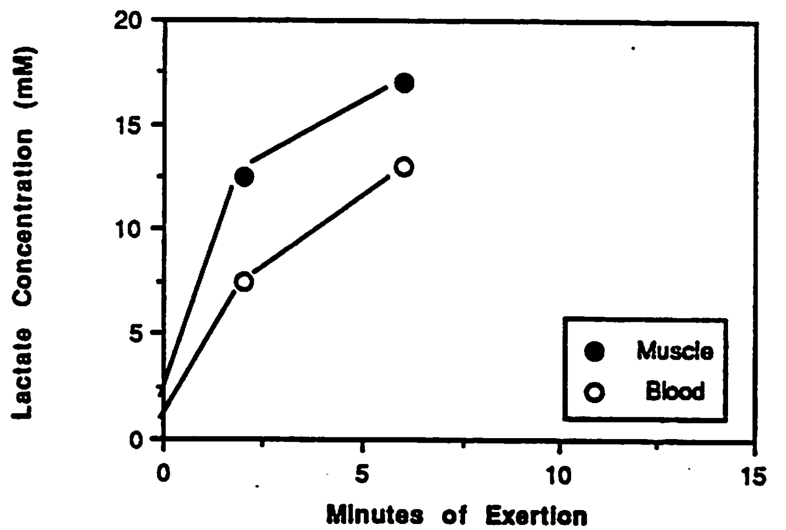


12

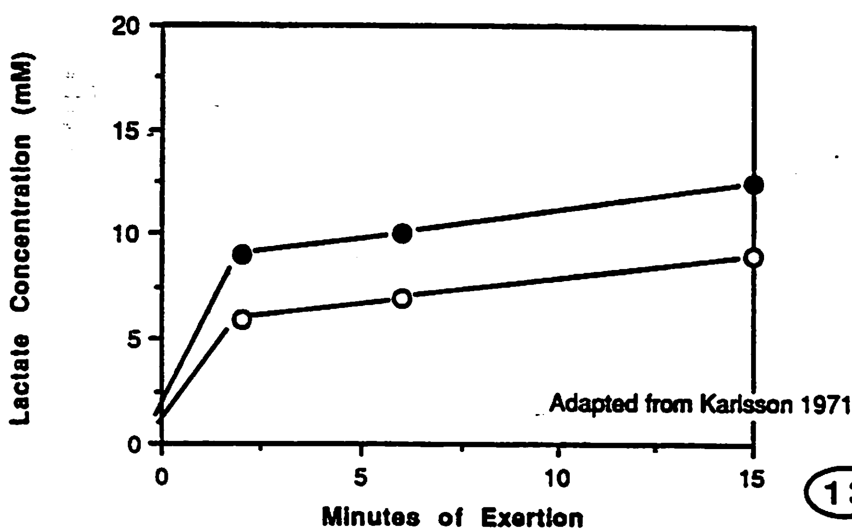
TWO MINUTES OF EXHAUSTIVE WORK



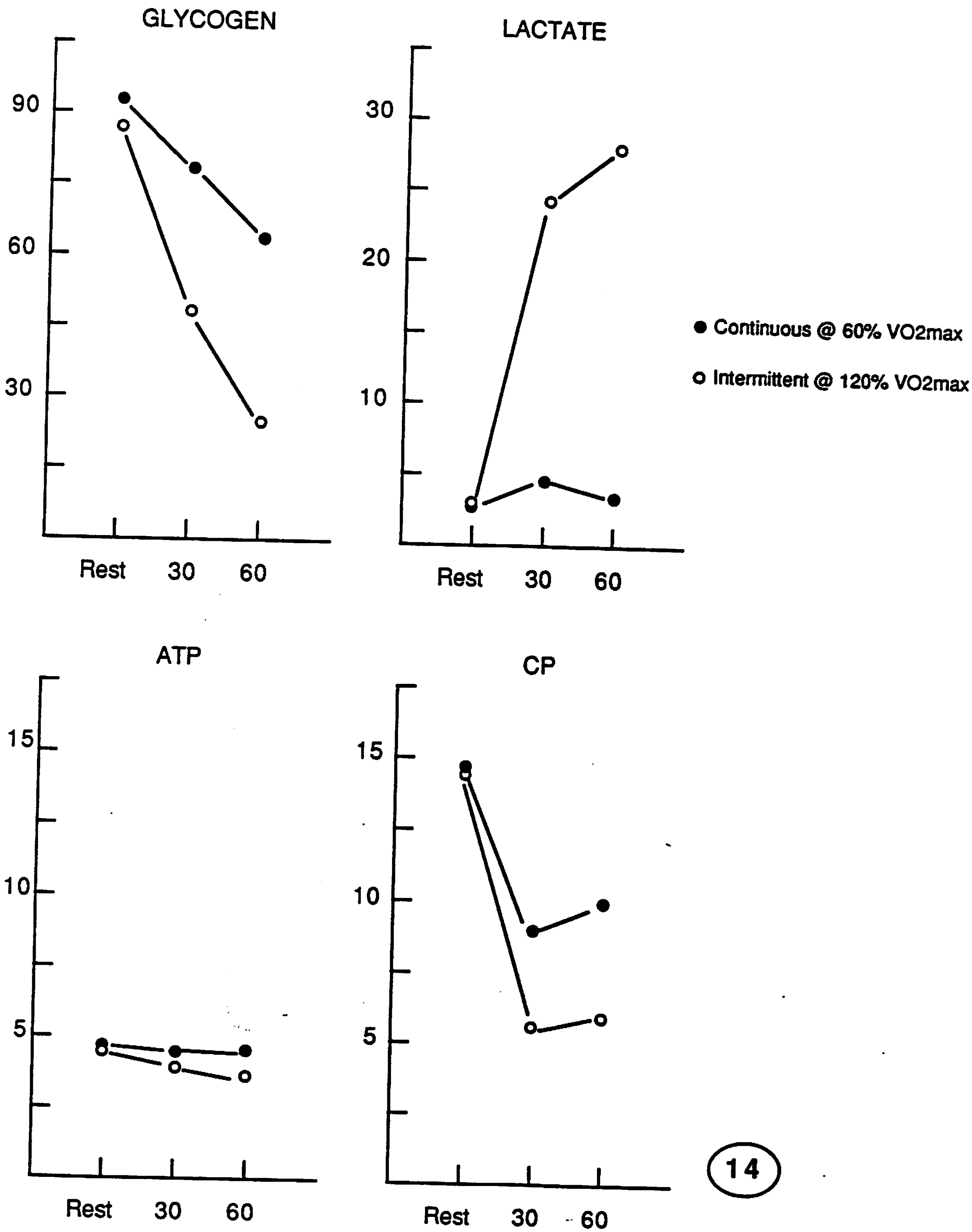
SIX MINUTES OF EXHAUSTIVE WORK



FIFTEEN MINUTES OF EXHAUSTIVE WORK

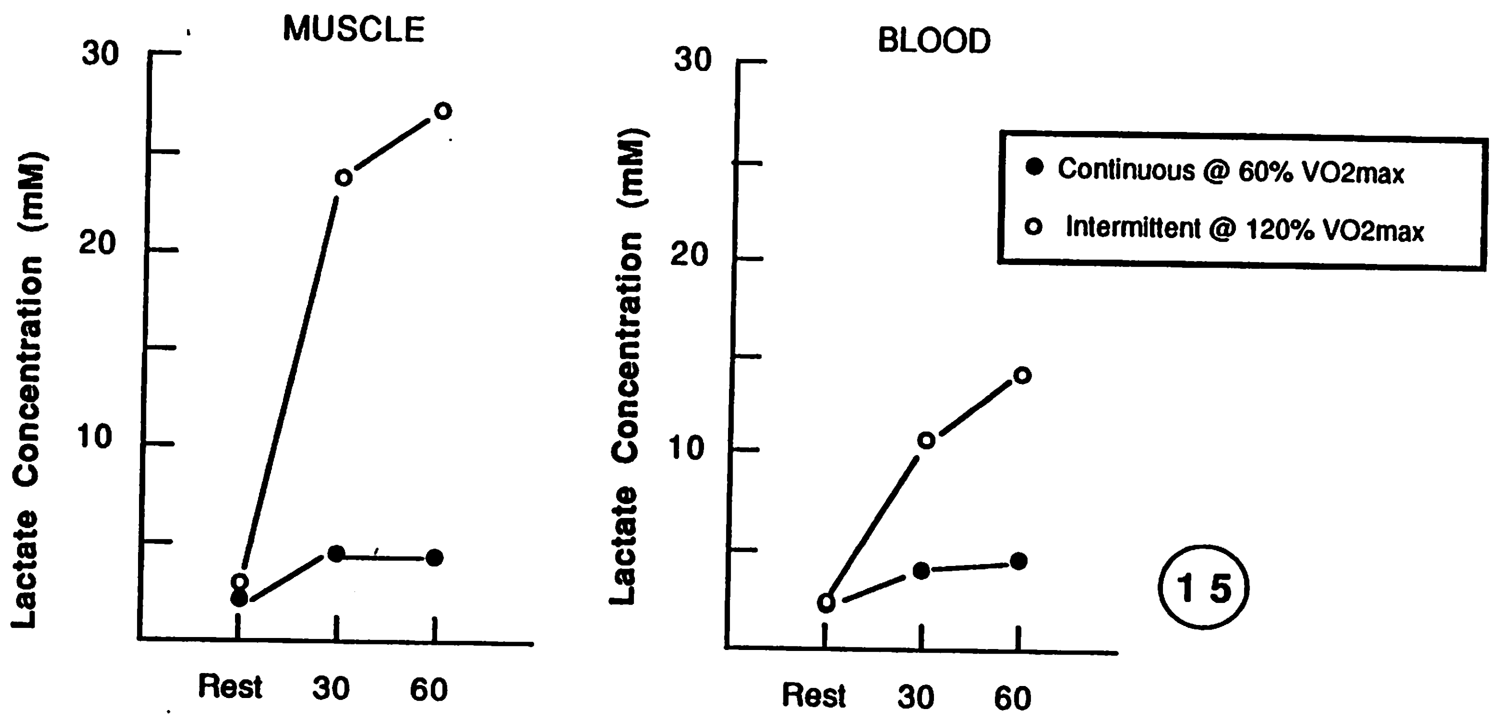


CHANGES IN MUSCLE METABOLITES DURING SKATING



Adapted from Green 1978

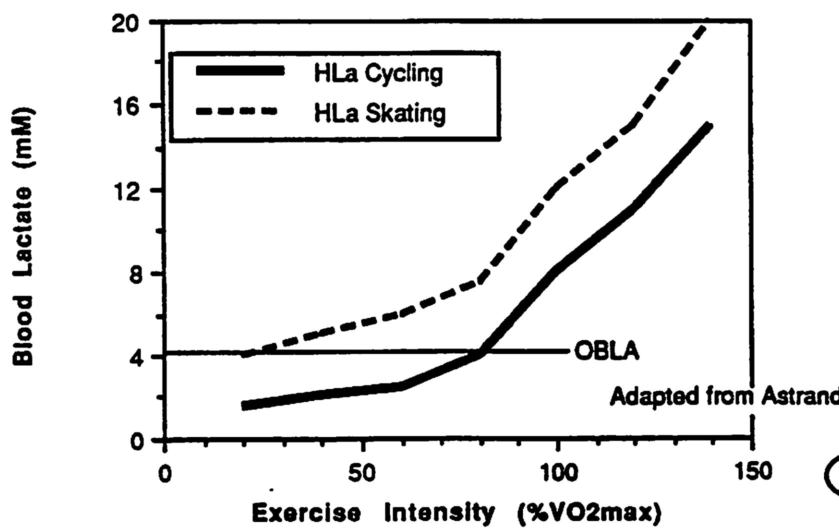
MUSCLE AND BLOOD LACTATE DURING SKATING(mM)



15

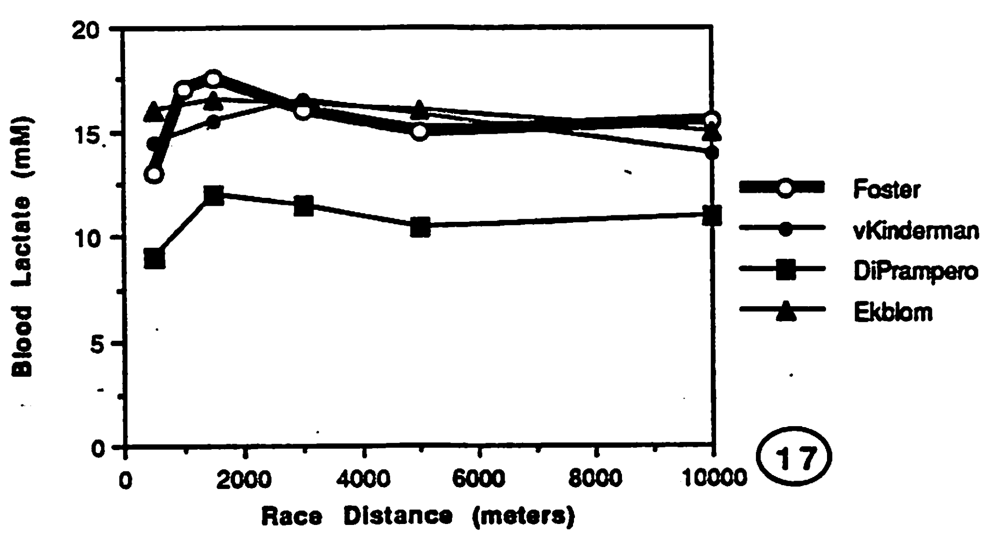
Adapted from Green 1978

BLOOD LACTATE CYCLING VS SKATING



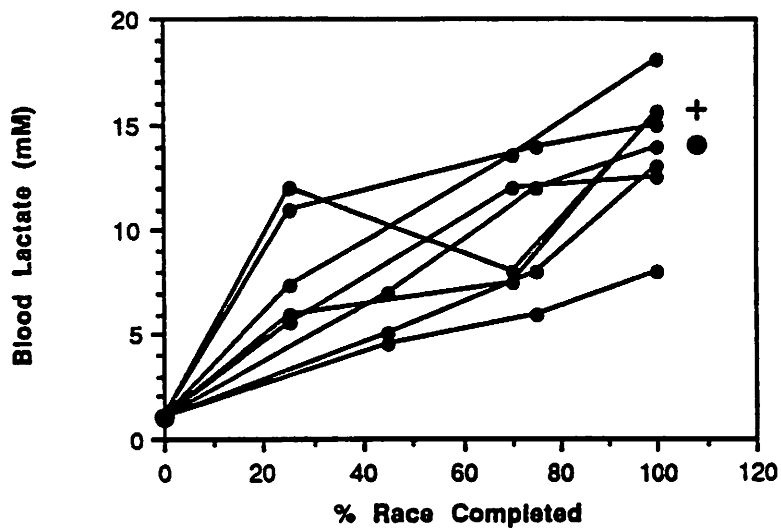
16

POST COMPETITION LACTATE



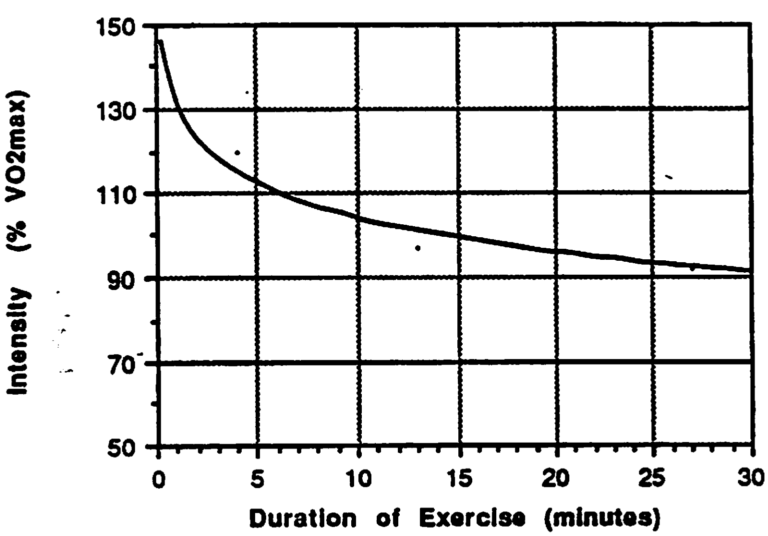
17

LACTATE ACCUMULATION 2000/3000 m ROLLER RACE

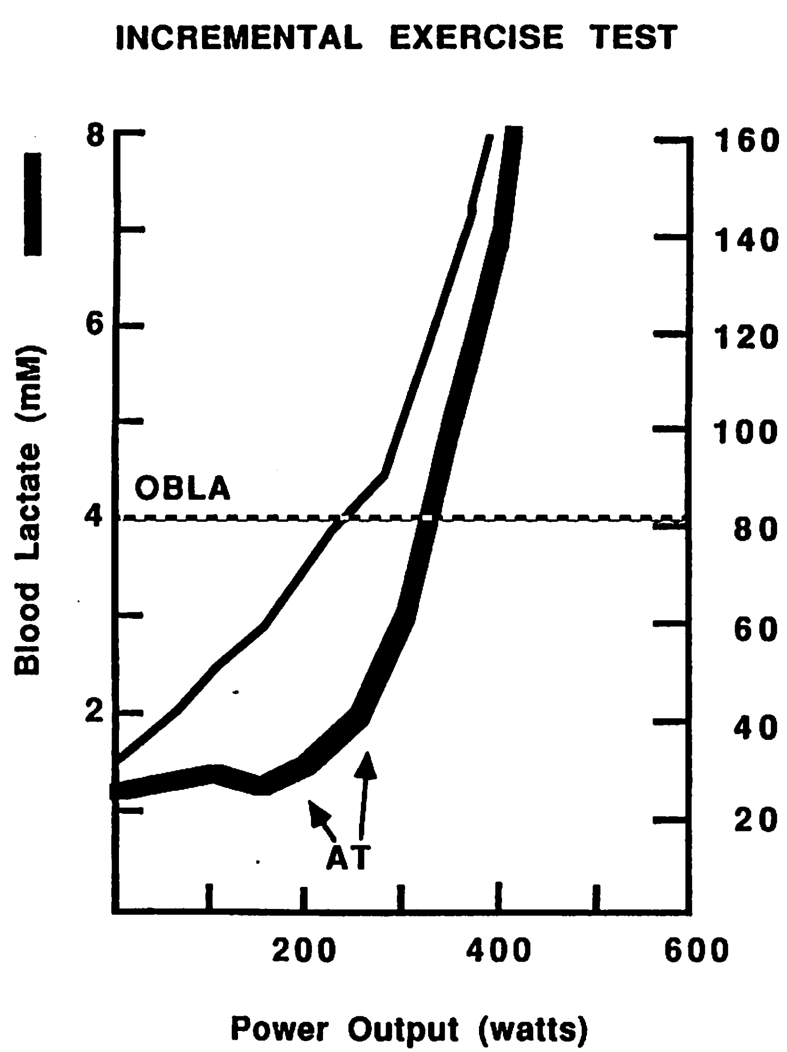


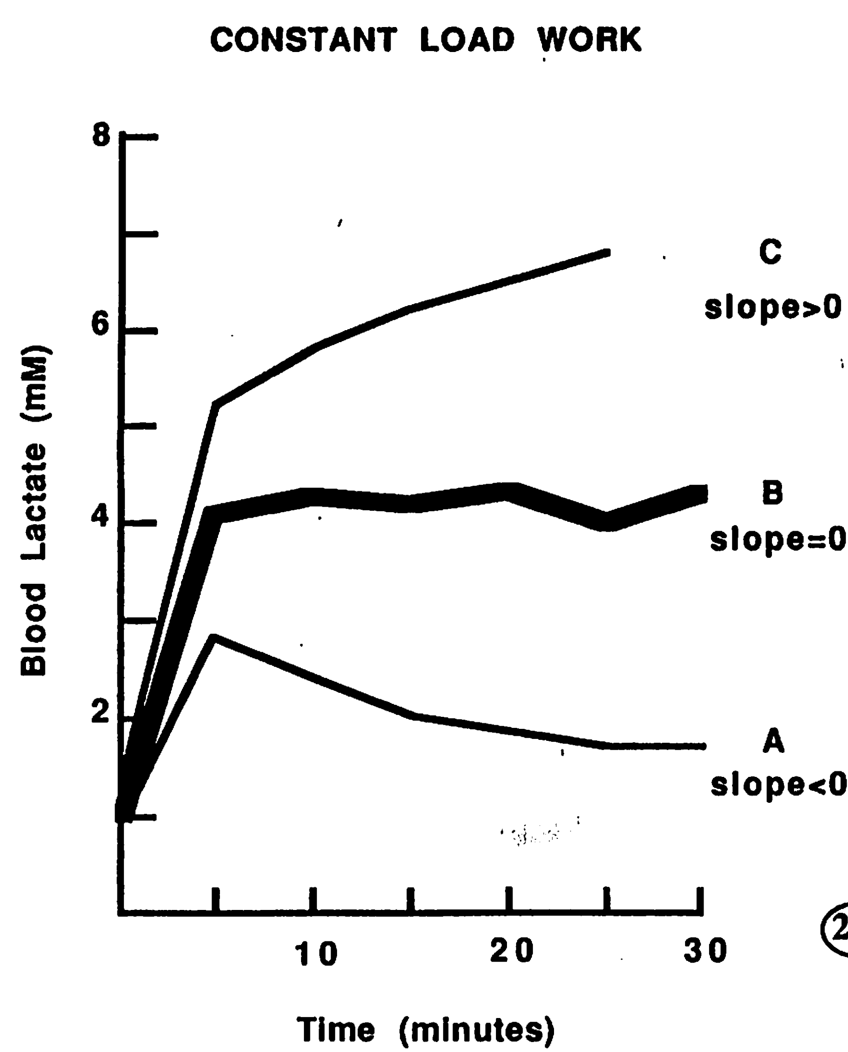
18

INTENSITY VS DURATION OF EXERCISE



19

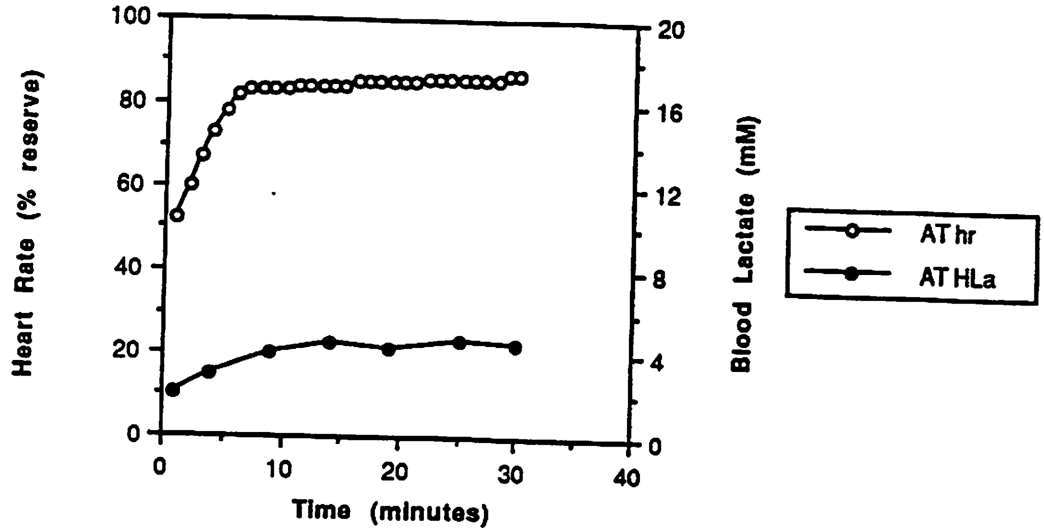

INCREMENTAL EXERCISE TEST
Blood Lactate (mM)
8
6
4
2
OBLA
AT
200
400
600
Power Output (watts)
160
140
120
100
80
60
40
20
Ventilation (liters/min)


CONSTANT LOAD WORK
Blood Lactate (mM)
8
6
4
2
C
slope>0
B
slope=0
A
slope<0
10
20
30
Time (minutes)

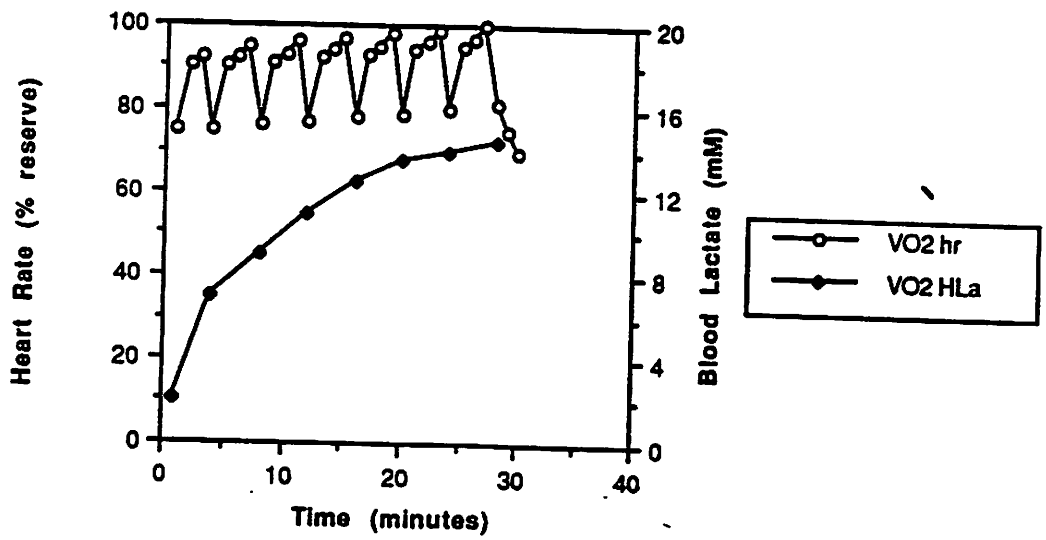
RUNNING PACING CHART

2 Mile TT	10x400m on 2:00	4x1200m	4 Mile AT
10:00	1:10	3:44	22:10
10:30	1:13	3:55	23:30
11:00	1:17	4:06	24:50
11:30	1:21	4:17	26:15
12:00	1:24	4:28	27:40
12:30	1:28	4:40	29:05
13:00	1:31	4:51	30:30
13:30	1:35	5:02	32:00
14:00	1:38	5:13	33:30
14:30	1:42	5:24	35:05
15:00	1:46	5:36	36:40
15:30	-----	5:46	38:15
16:00	-----	5:58	40:00

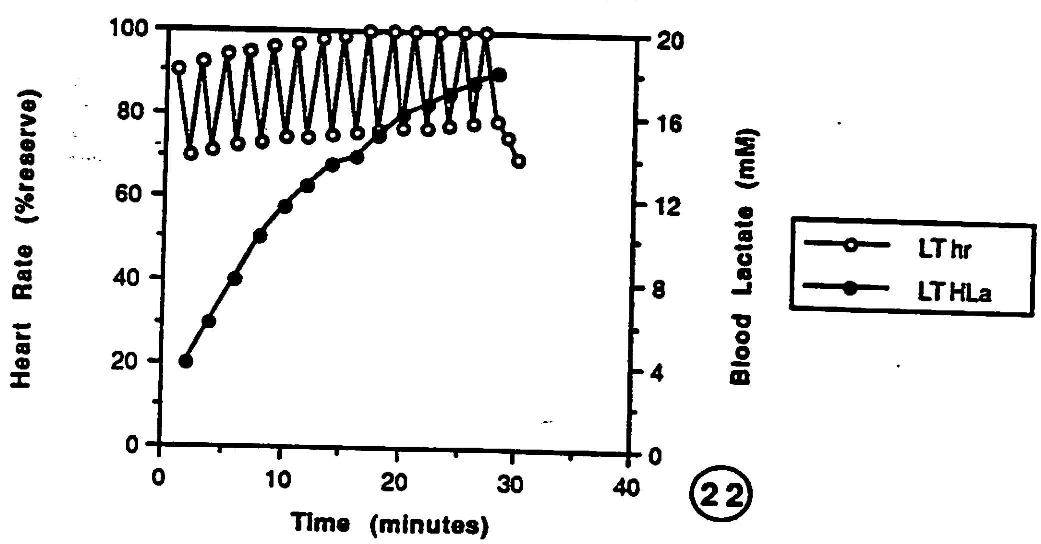
ANAEROBIC THRESHOLD RUN



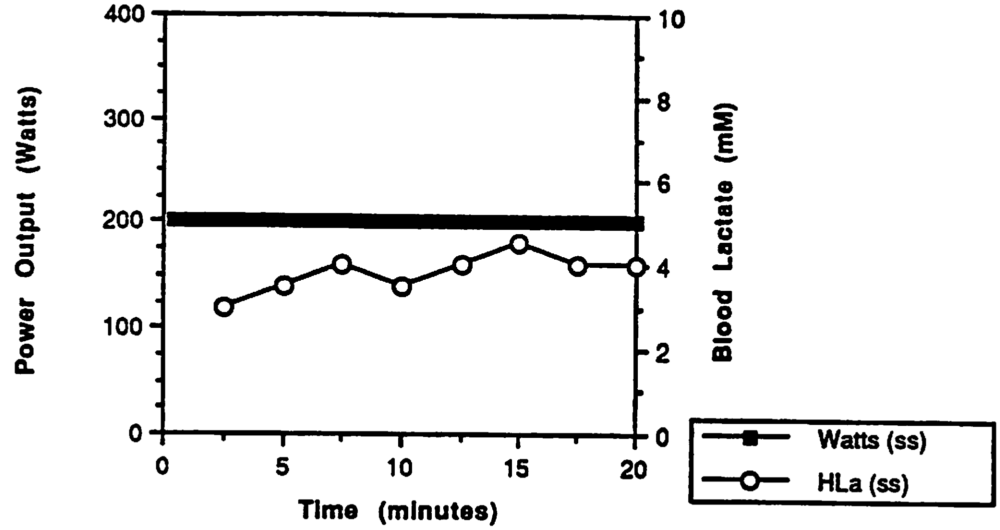
VO2max RUN



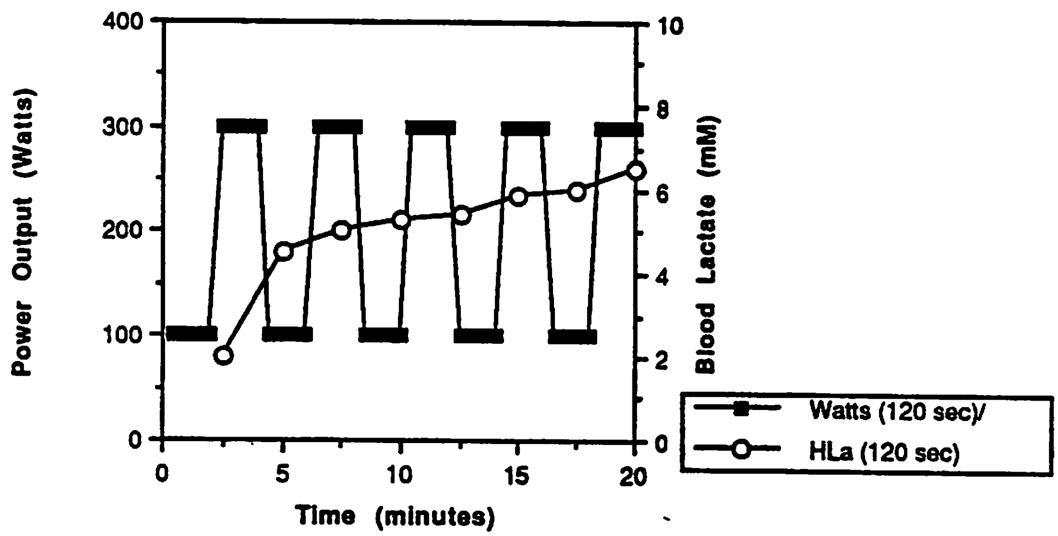
LACTATE TOLERANCE RUN



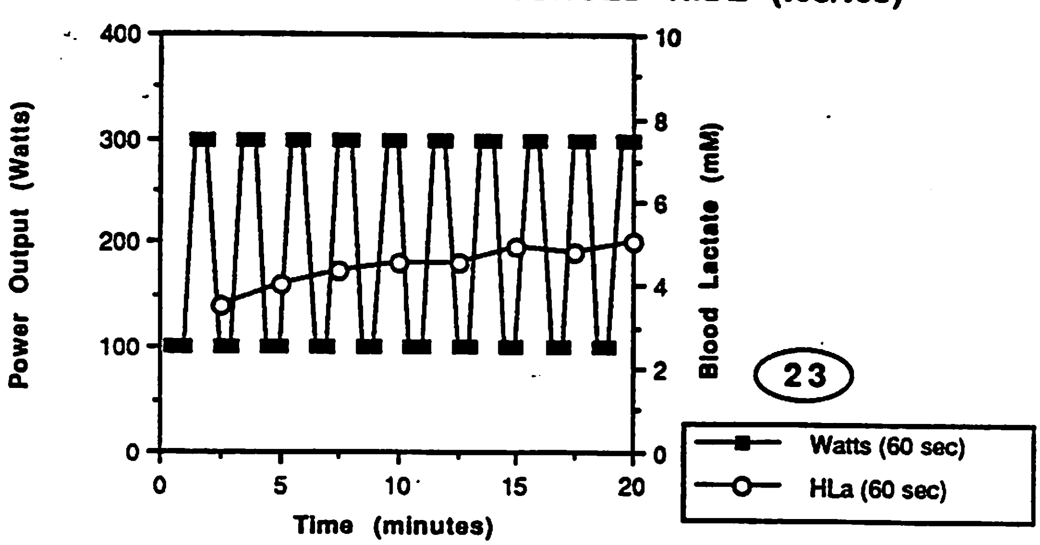
STEADY STATE ANAEROBIC THRESHOLD RIDE



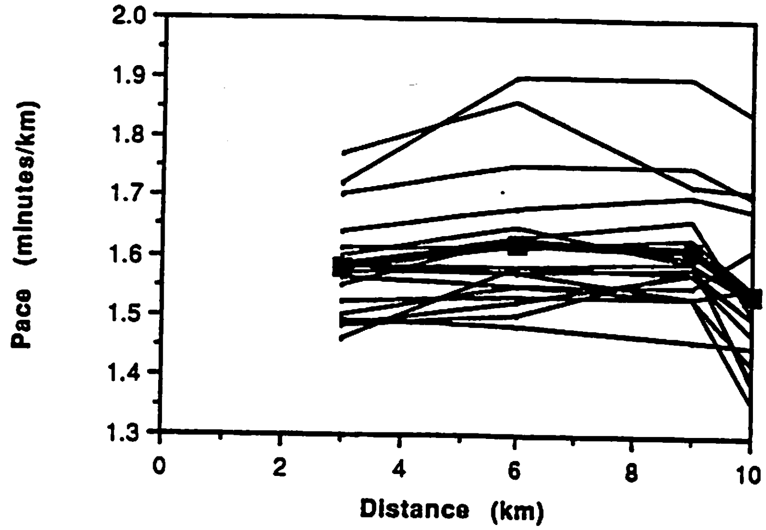
INTERVAL ANAEROBIC THRESHOLD RIDE (2:00/2:00)

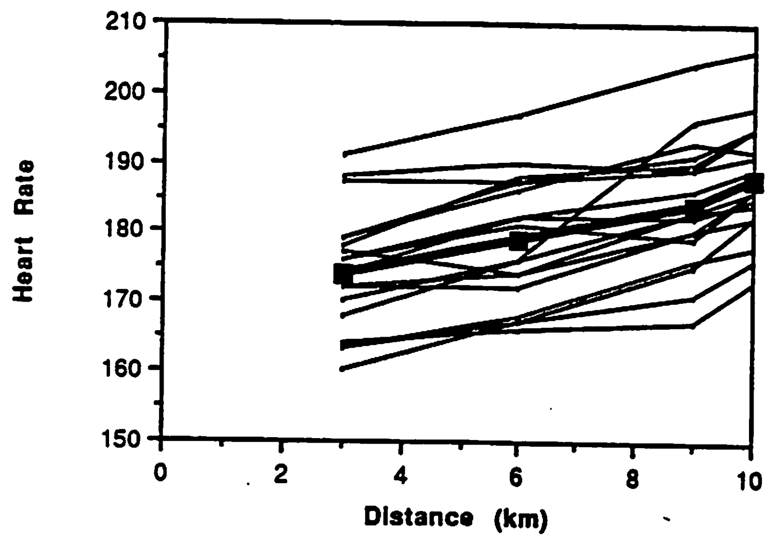


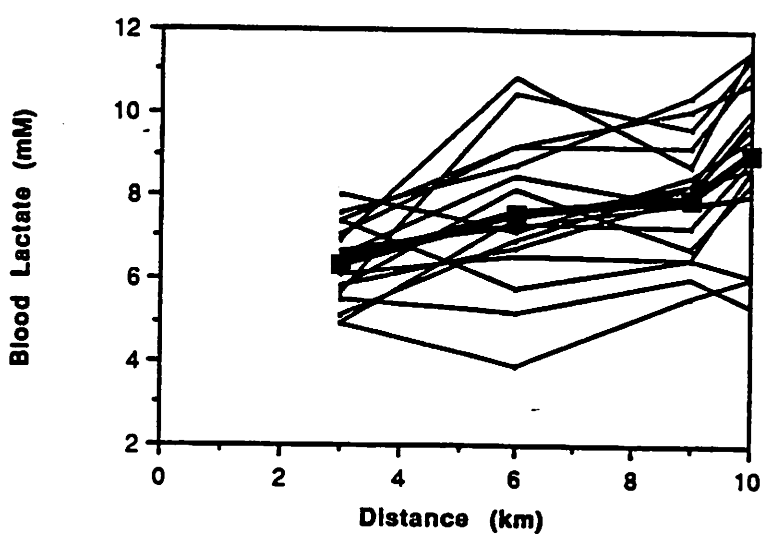
INTERVAL ANAEROBIC THRESHOLD RIDE (:60/:60)



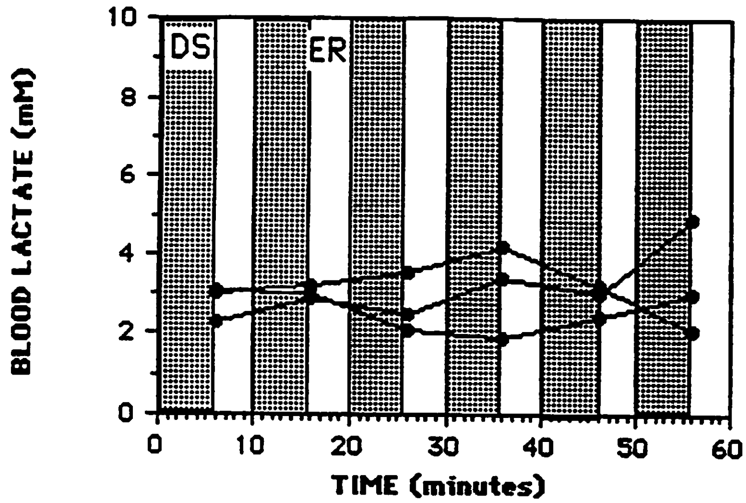
10 KM TIME TRIAL





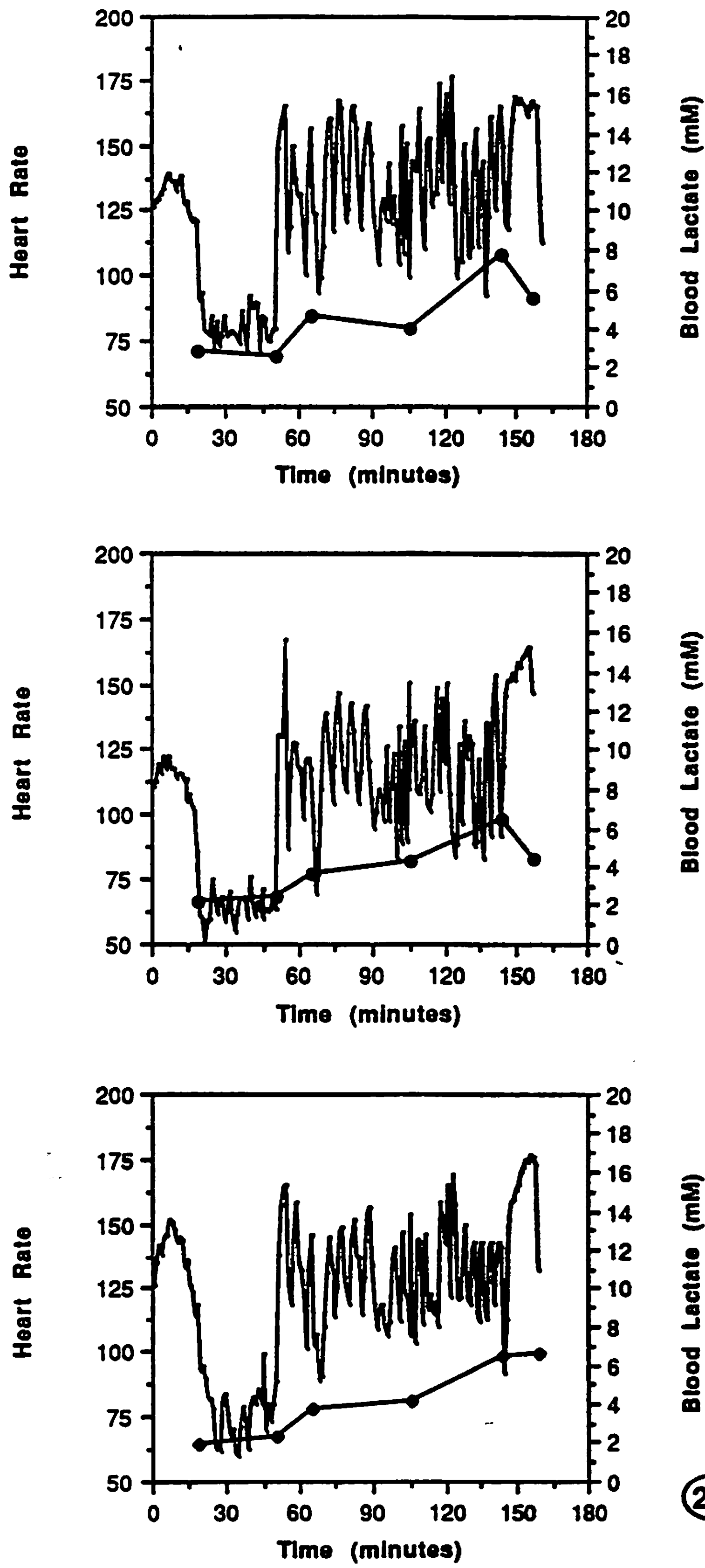


ENDURANCE RUN (4:00) /DRY SKATE (6:00)

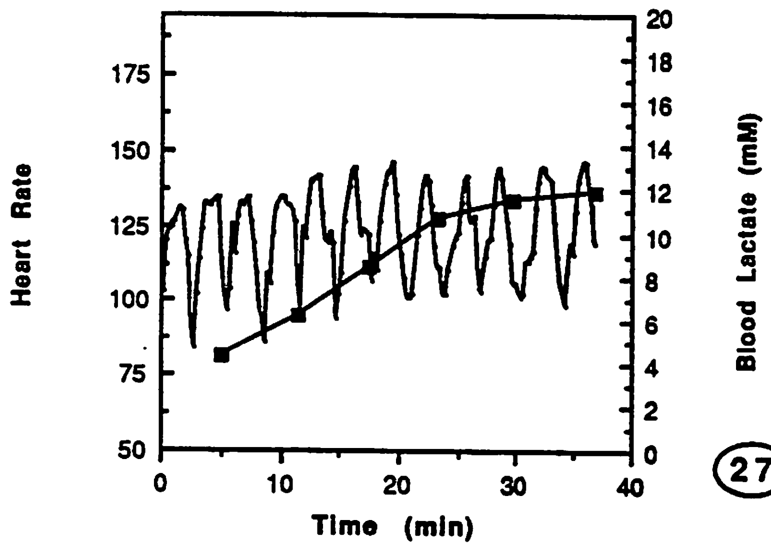


25

FARTLIK WORKOUT

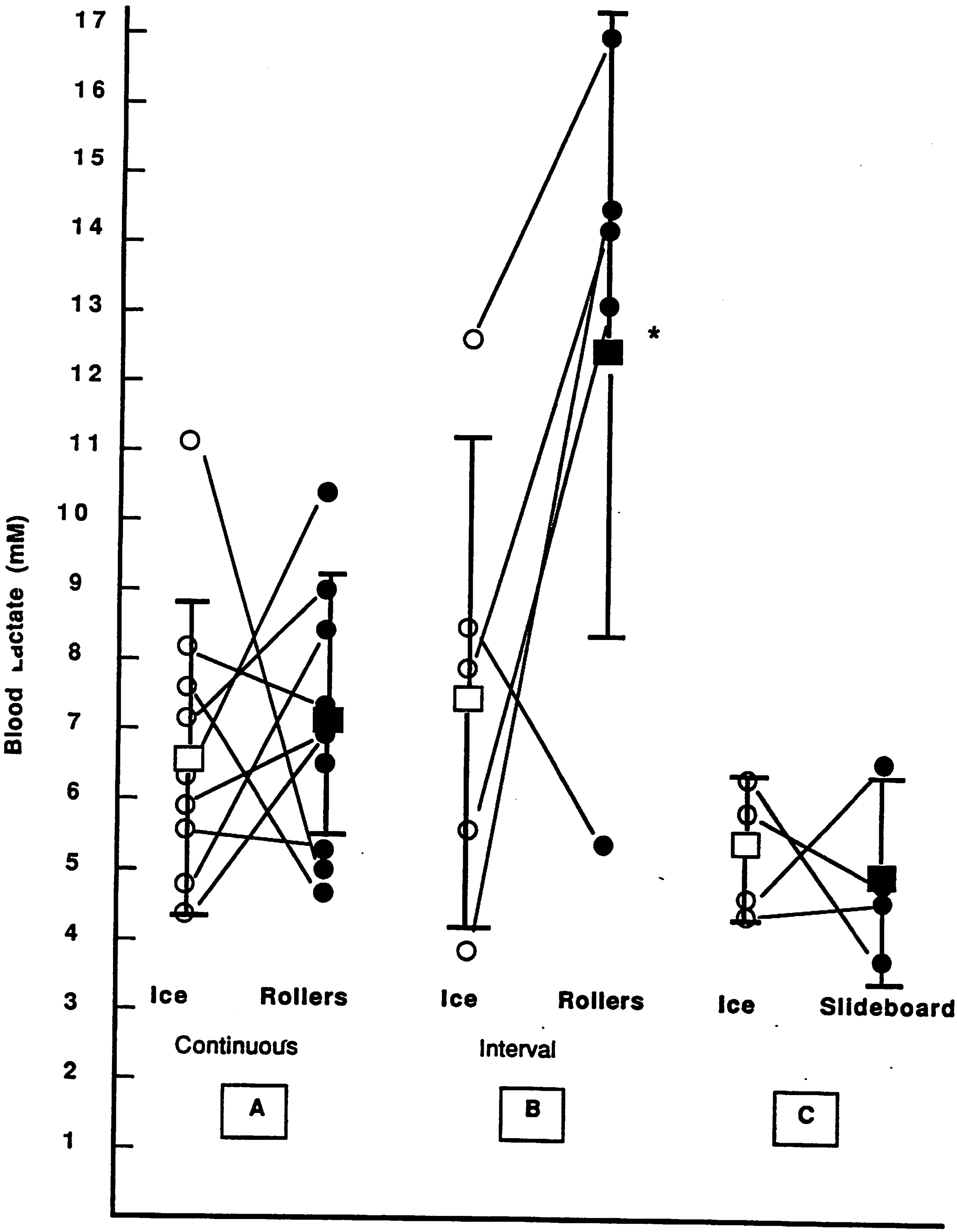


WOODER SQUATS

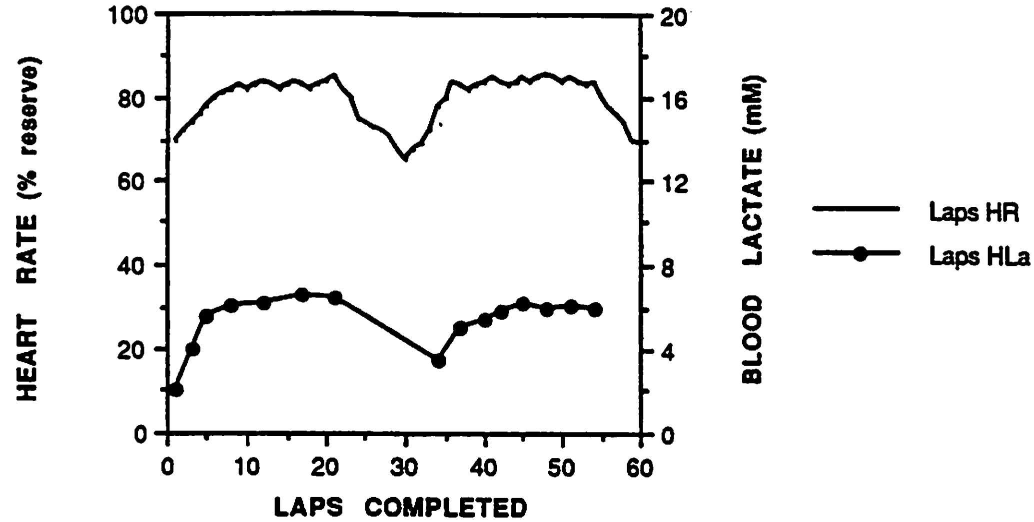


27

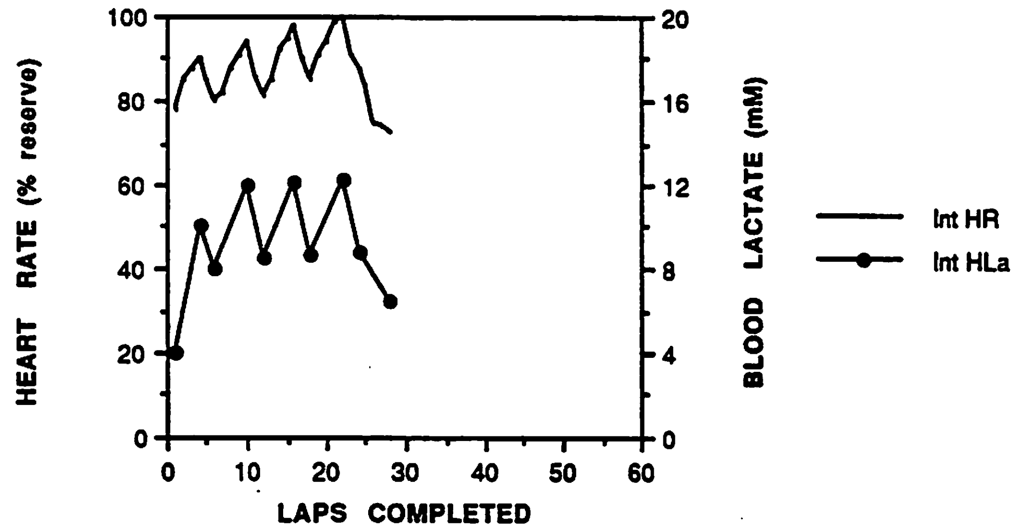
ROLLERS AND SLIDEBOARD VS ICE SKATING



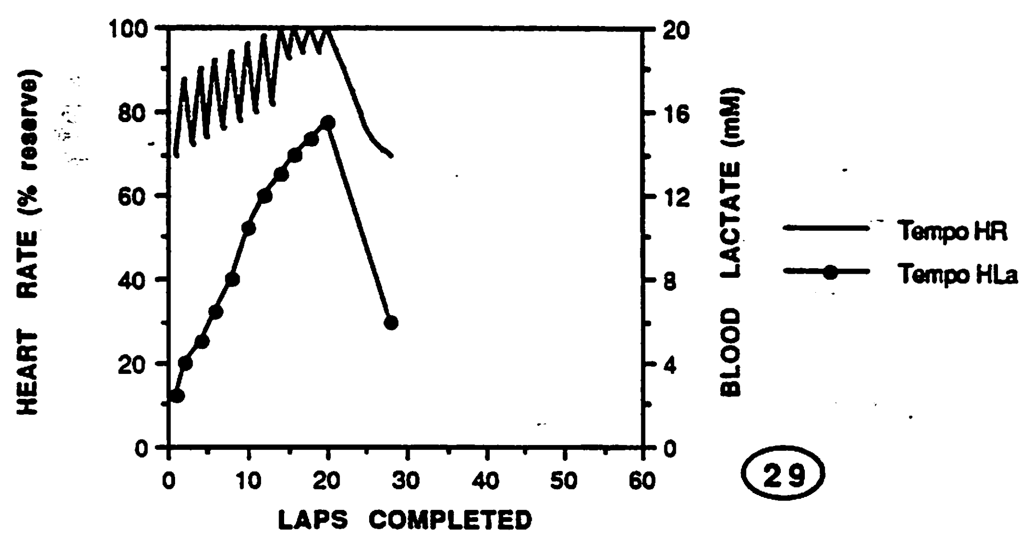
2 x 20 Laps @ Anaerobic Threshold Pace

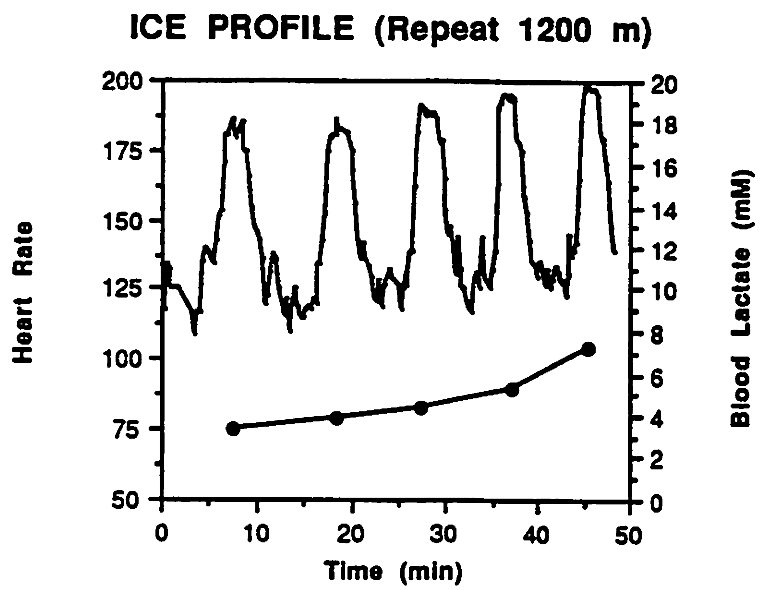


4 x 4 Laps/2 Laps @ 5000m Pace

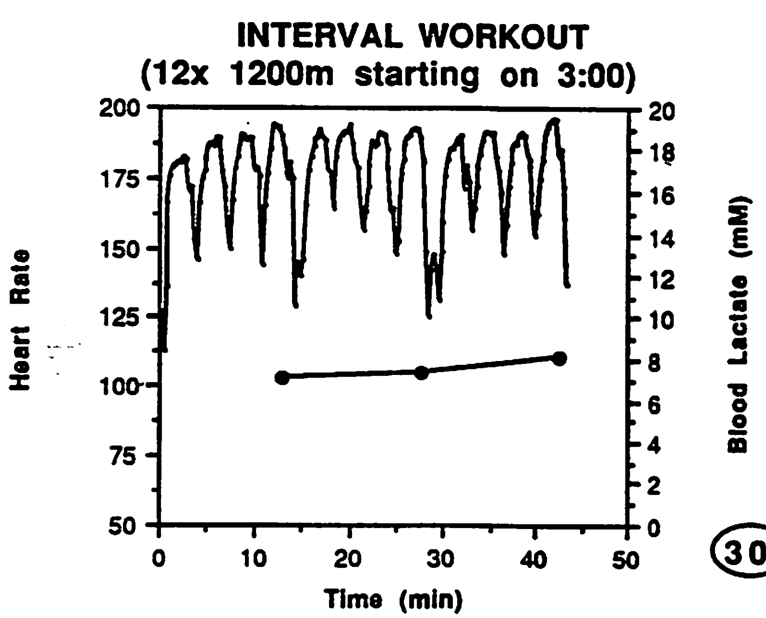


10 X 1 Lap/ 1 Lap @ 1500 m Pace



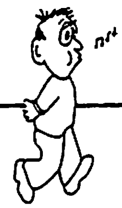


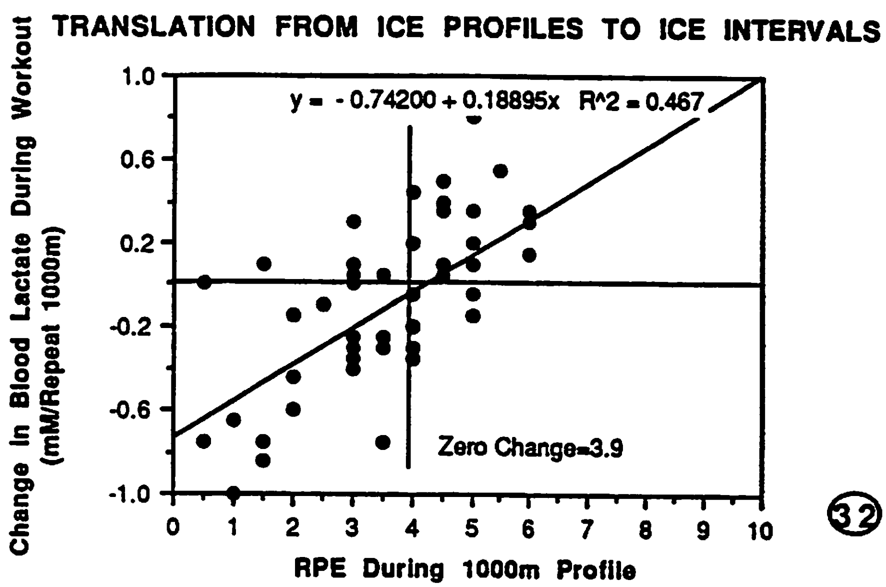
ICE PROFILE (Repeat 1200 m)
Heart Rate
Blood Lactate (mM)
Time (min)
200
175
150
125
100
75
50
20
18
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50



INTERVAL WORKOUT
(12x 1200m starting on 3:00)
Heart Rate
Blood Lactate (mM)
Time (min)
200
175
150
125
100
75
50
20
18
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50

PERCEIVED EXERTION SCALE

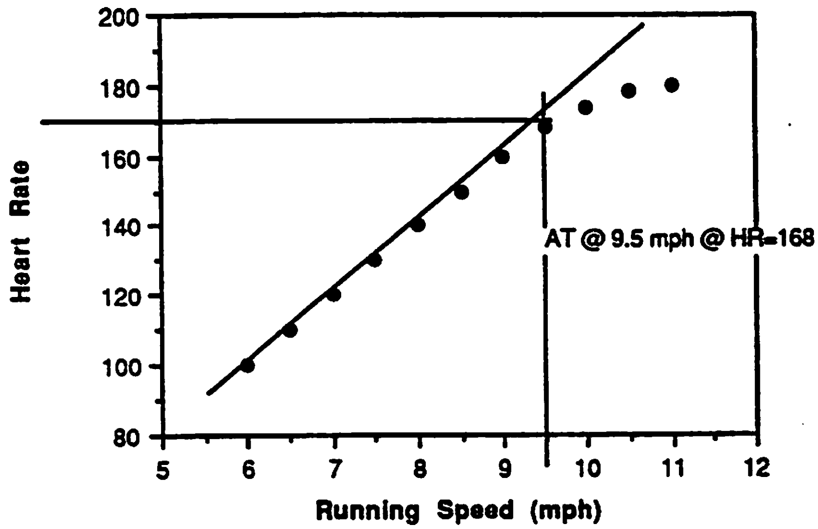
0.0		NO EFFORT (STANDING AT REST)
0.5		VERY , VERY EASY
1		VERY EASY
2		EASY
3		MODERATE
4		SOMEWHAT HARD
5		HARD
6		
7		VERY HARD
8		
9		VERY , VERY HARD (NEARLY MAXIMAL)
10		MAXIMAL

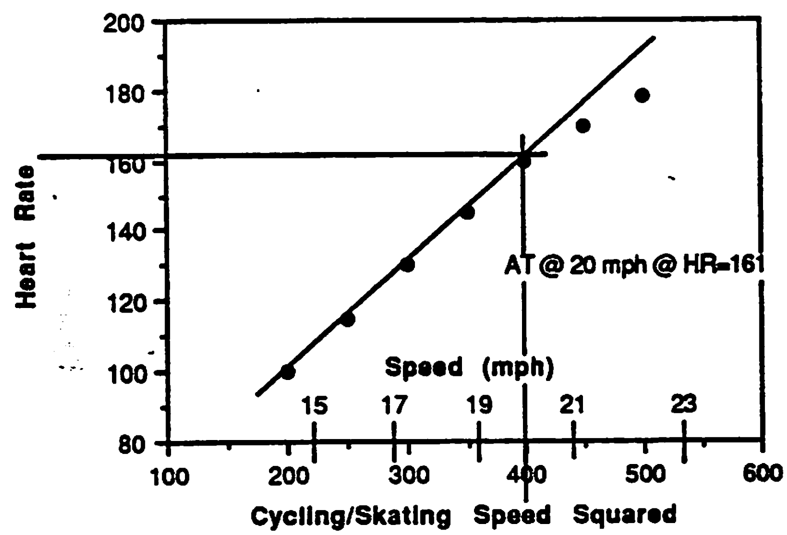


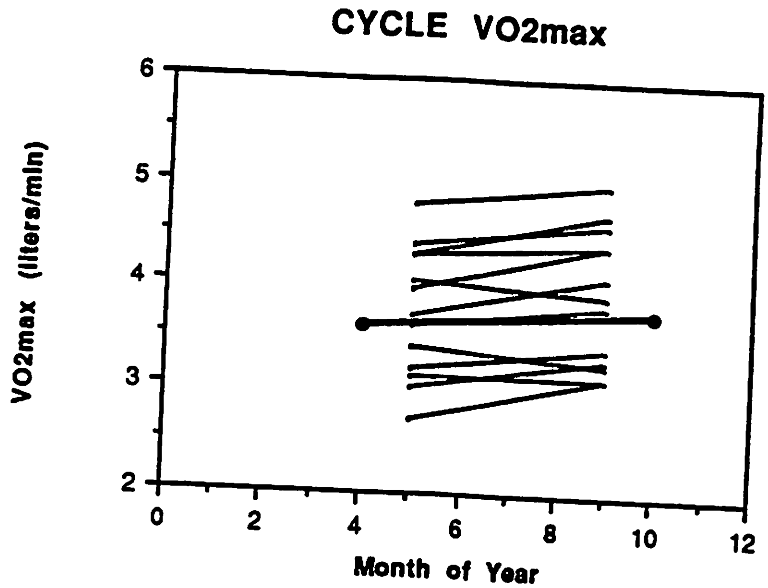
TRANSLATION FROM ICE PROFILES TO ICE INTERVALS
y = - 0.74200 + 0.18895x R^2 = 0.467
Zero Change=3.9
1.0
0.6
0.2
-0.2
-0.6
-1.0
0
1
2
3
4
5
6
7
8
9
10
RPE During 1000m Profile
Change In Blood Lactate During Workout (mM/Repeat 1000m)

32

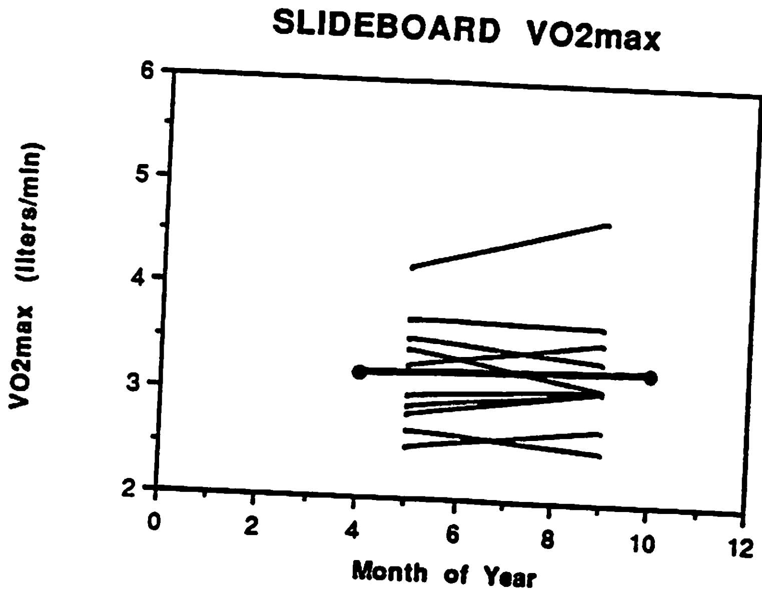
CONCONI METHOD FOR ANAEROBIC THRESHOLD



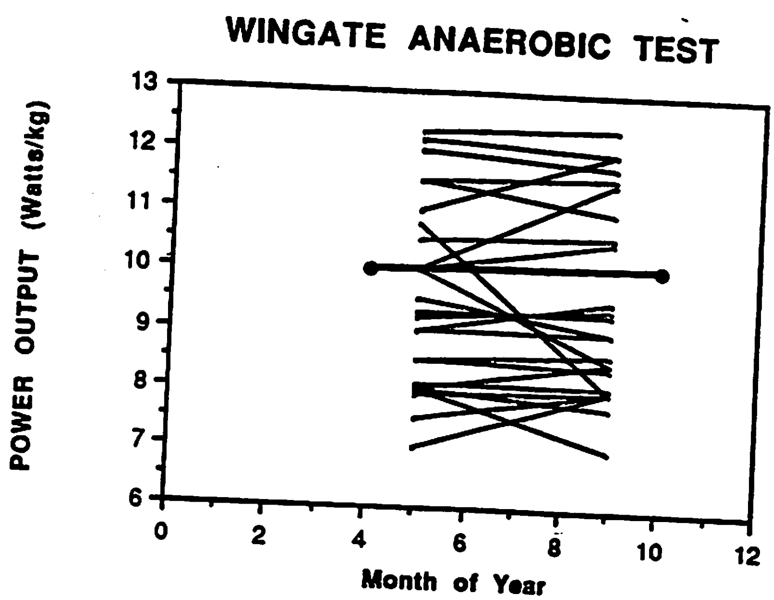



CYCLE VO2max
VO2max (liters/min)
Month of Year

34

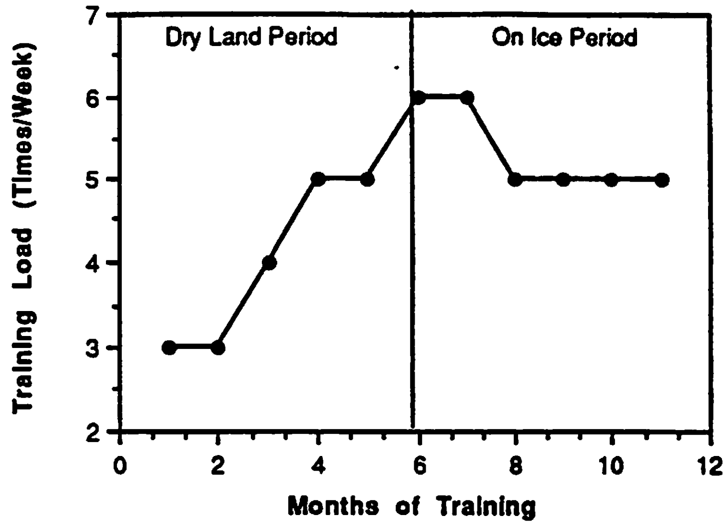

SLIDEBOARD VO2max
VO2max (liters/min)
Month of Year

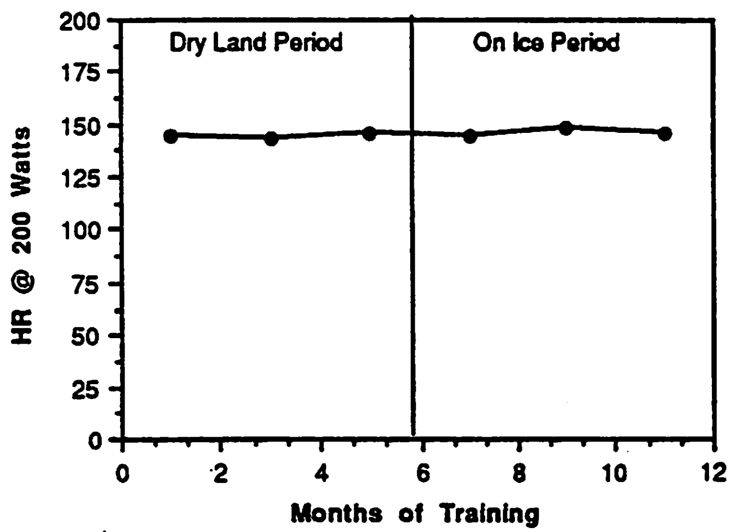
35

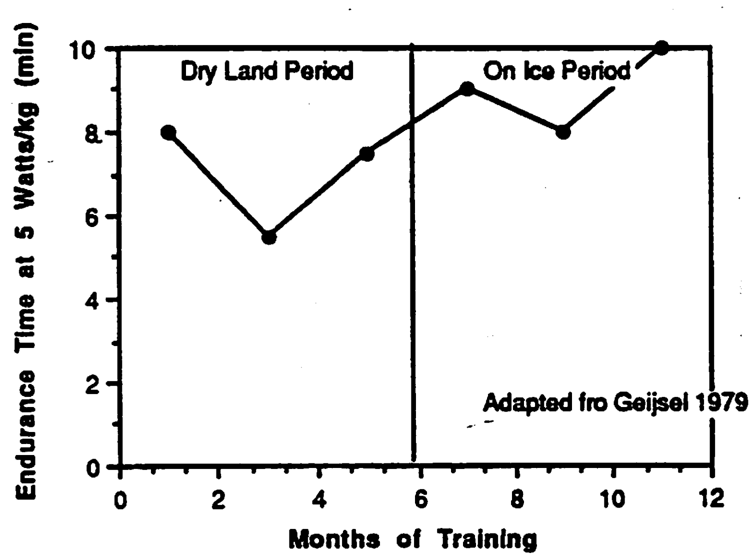

WINGATE ANAEROBIC TEST
POWER OUTPUT (Watts/kg)
Month of Year

36

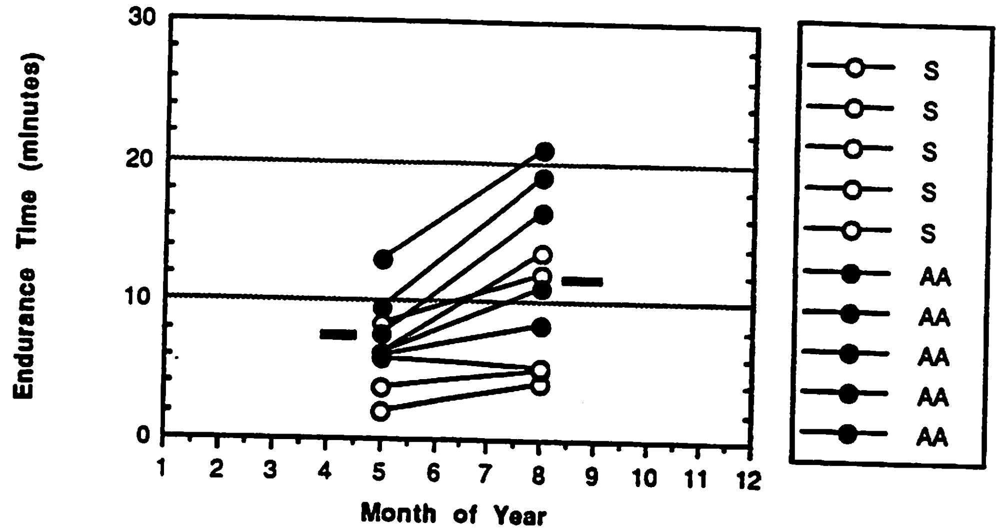
CONDITIONING IN MARATHON SKATERS



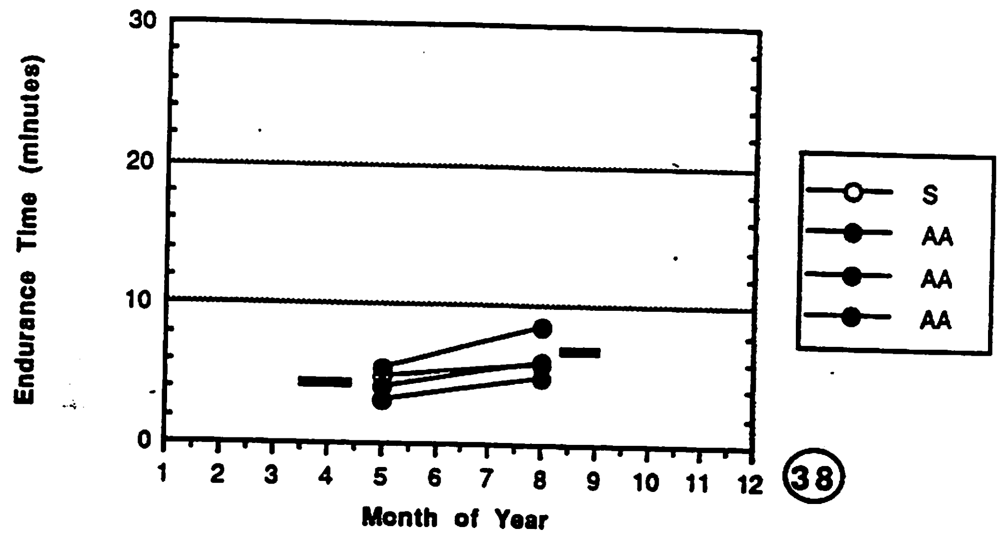


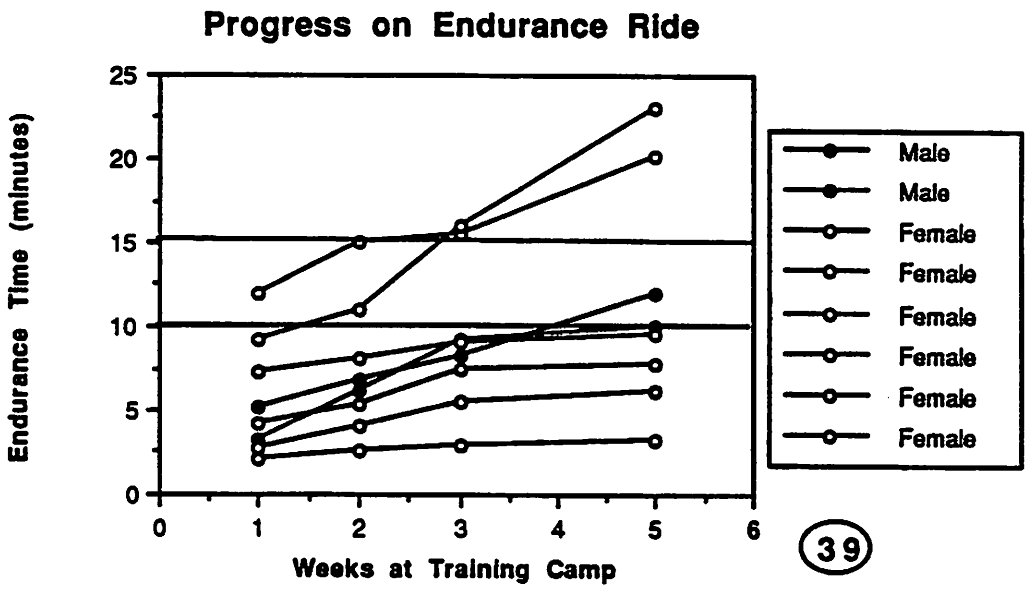


SUCCESSFUL SKATERS



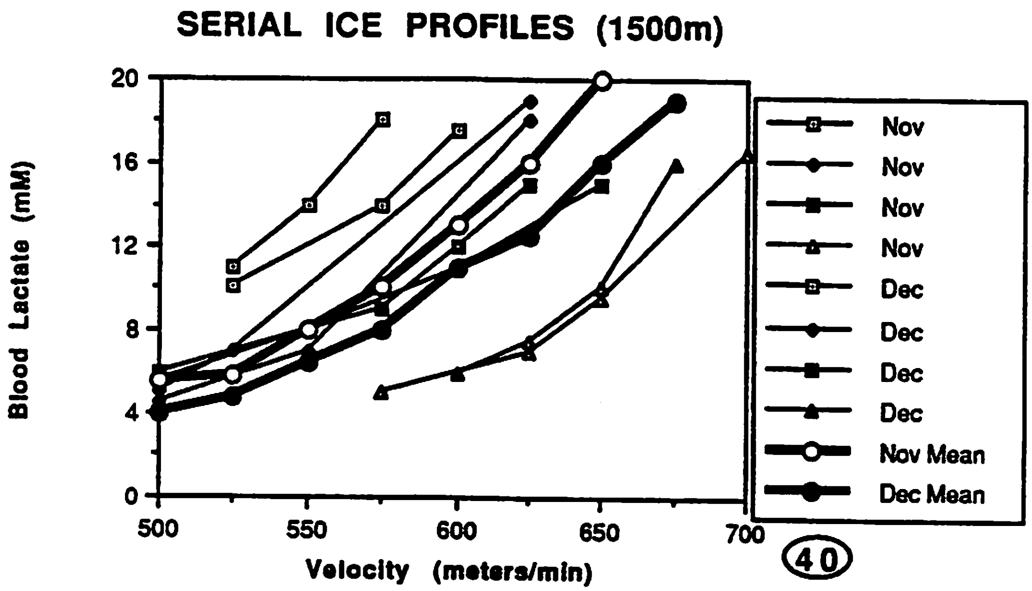
UNSUCCESSFUL SKATERS





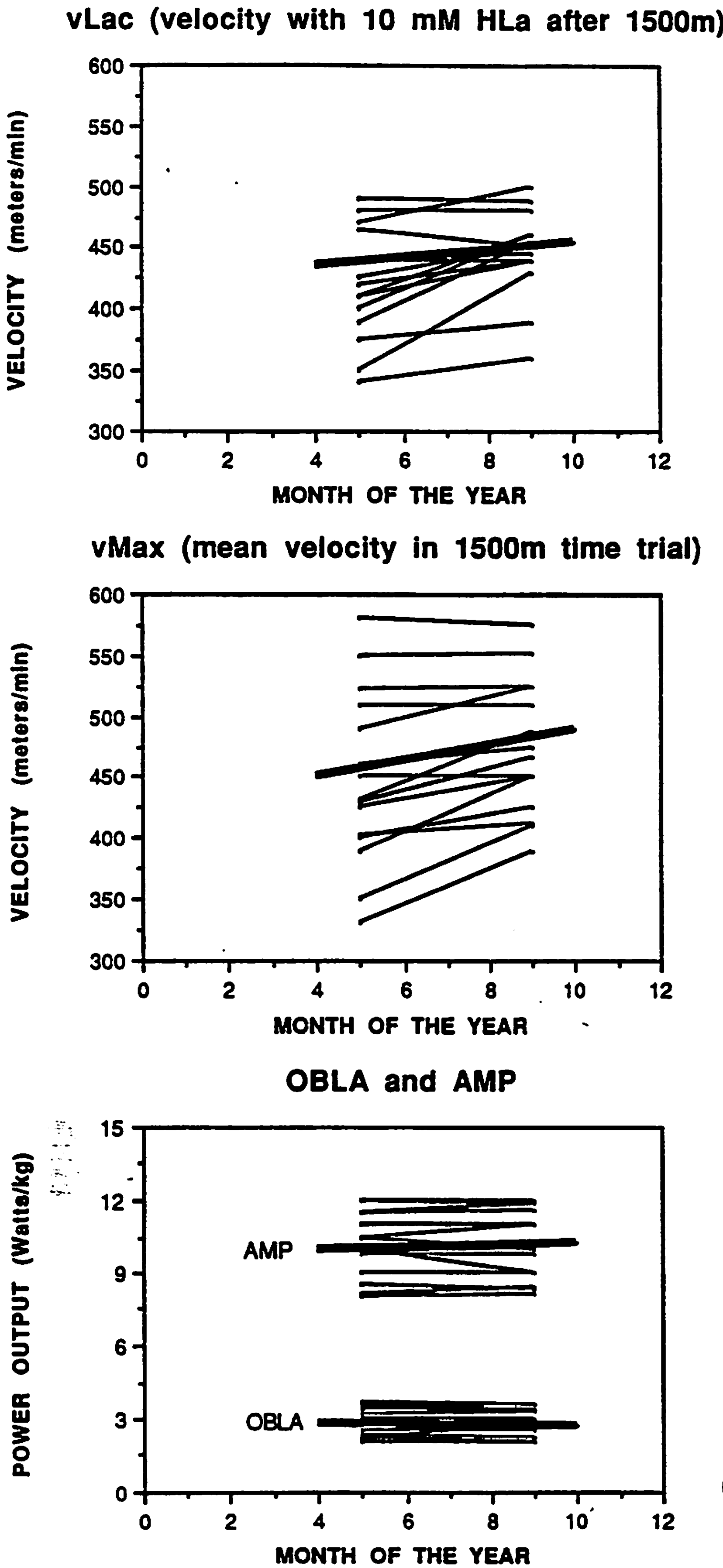
Progress on Endurance Ride
Endurance Time (minutes)
25
20
15
10
5
0
0
1
2
3
4
5
6
Weeks at Training Camp
Male
Male
Female
Female
Female
Female
Female
Female

39



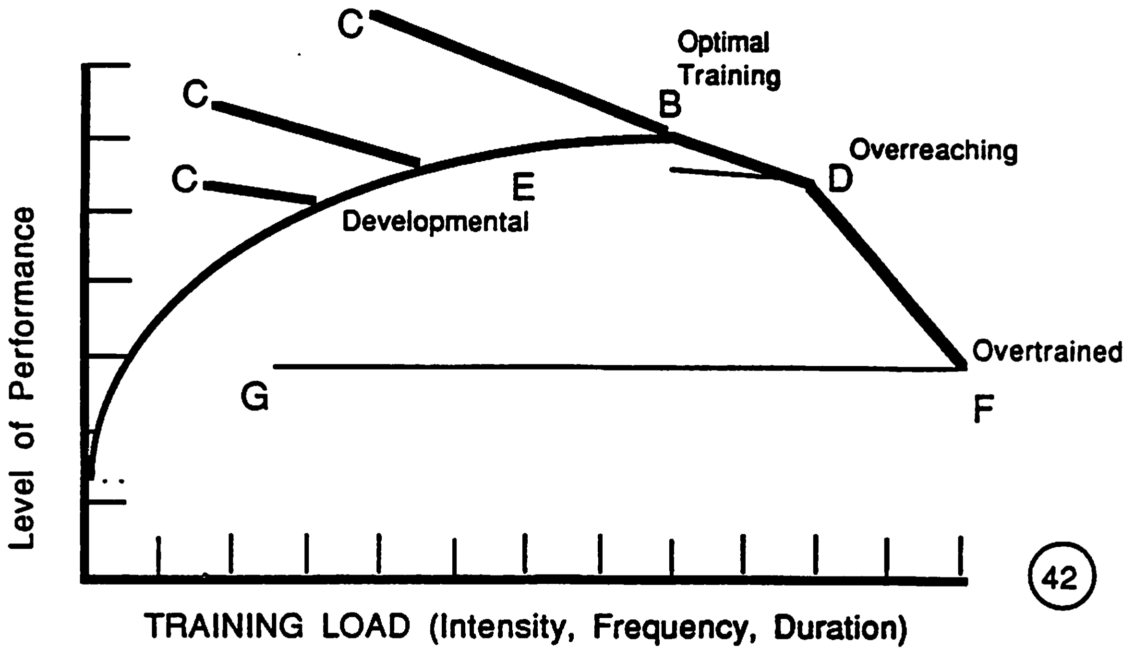
SERIAL ICE PROFILES (1500m)
Blood Lactate (mM)
20
16
12
8
4
0
500
550
600
650
700
Velocity (meters/min)
Nov
Nov
Nov
Nov
Dec
Dec
Dec
Dec
Nov Mean
Dec Mean

40



vLac (velocity with 10 mM HLa after 1500m)
VELOCITY (meters/min)
MONTH OF THE YEAR
vMax (mean velocity in 1500m time trial)
VELOCITY (meters/min)
MONTH OF THE YEAR
OBLA and AMP
POWER OUTPUT (Watts/kg)
AMP
OBLA
MONTH OF THE YEAR

RESPONSES TO TRAINING, OVERTRAINING AND TAPERING



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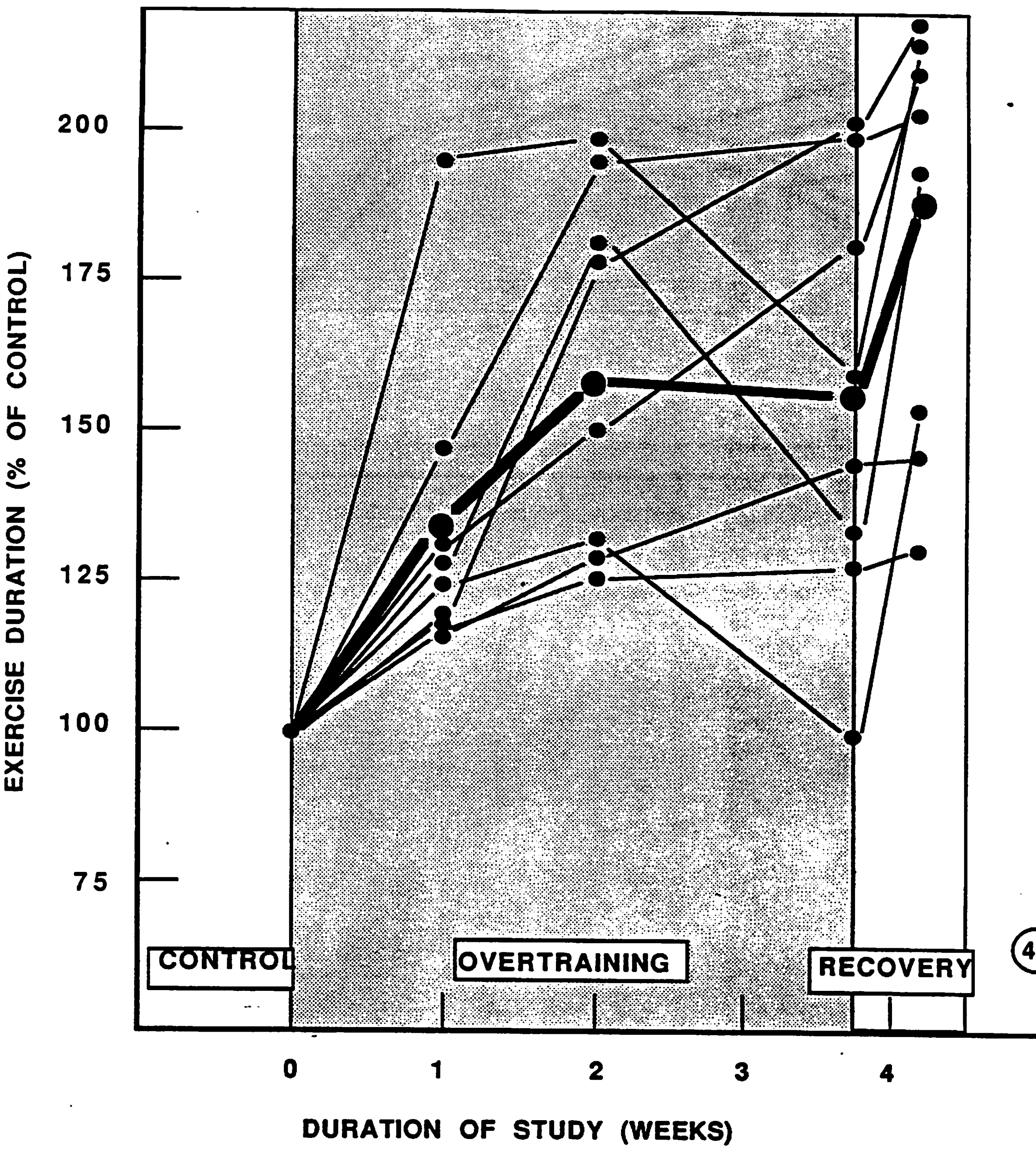
OVERTRAINING IN SPEED SKATERS

Summary Protocol and Results



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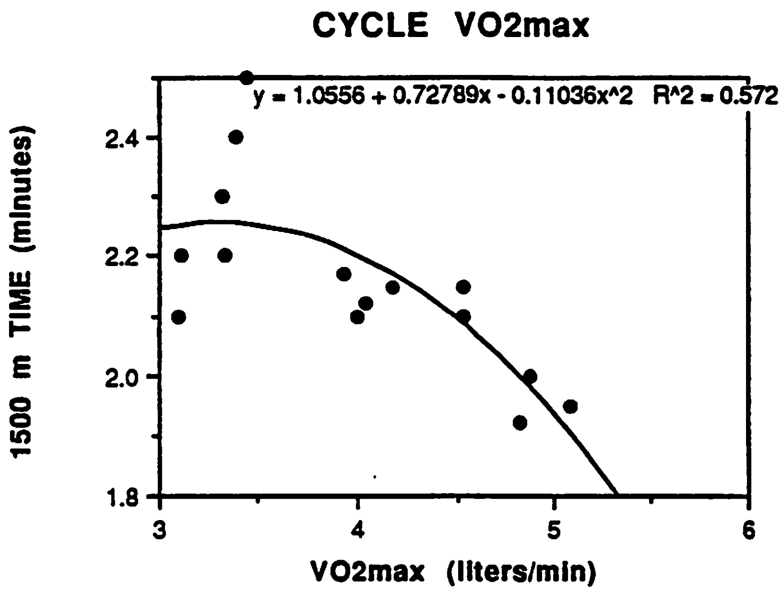
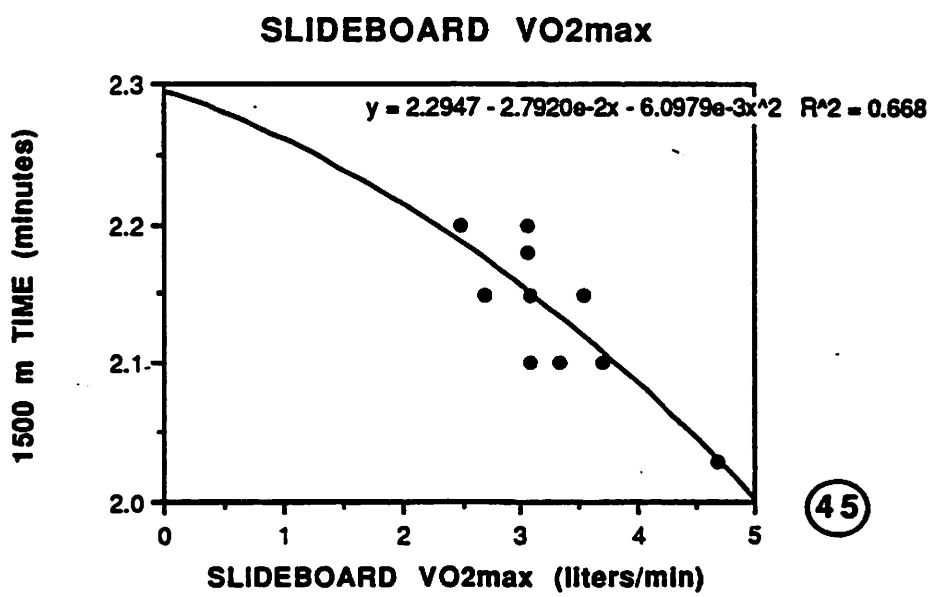


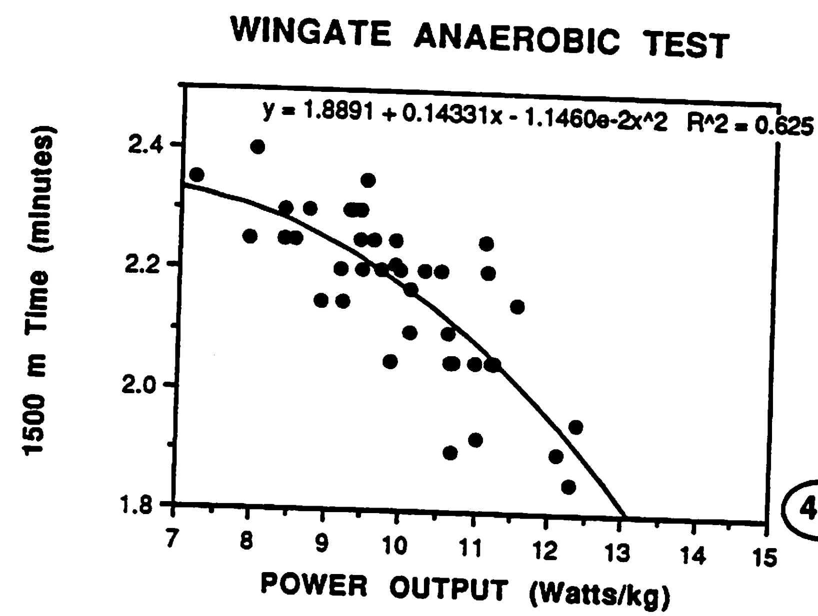
CYCLE VO2max
y = 1.0556 + 0.72789x - 0.11036x^2 R^2 = 0.572
1500 m TIME (minutes)
2.4
2.2
2.0
1.8
3
4
5
6
VO2max (liters/min)

44

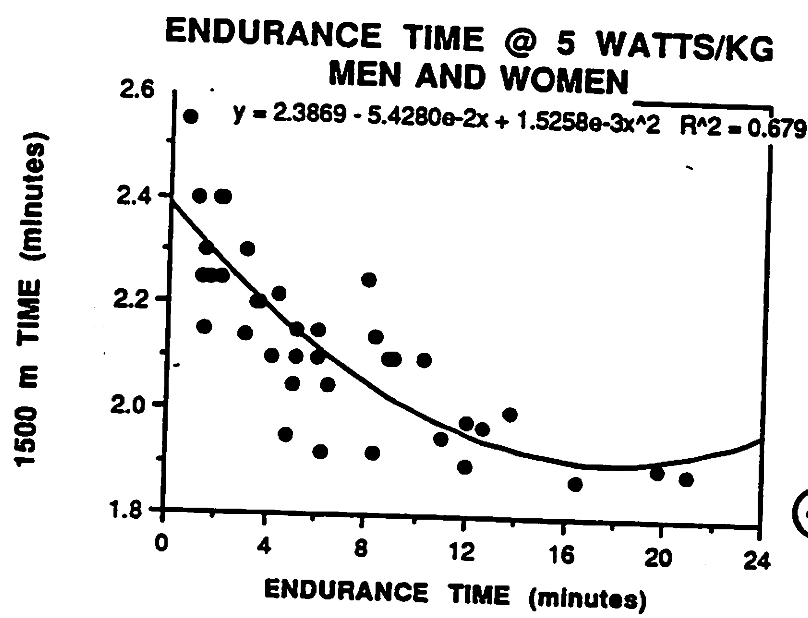


SLIDEBOARD VO2max
y = 2.2947 - 2.7920e-2x - 6.0979e-3x^2 R^2 = 0.668
1500 m TIME (minutes)
2.3
2.2
2.1
2.0
0
1
2
3
4
5
SLIDEBOARD VO2max (liters/min)

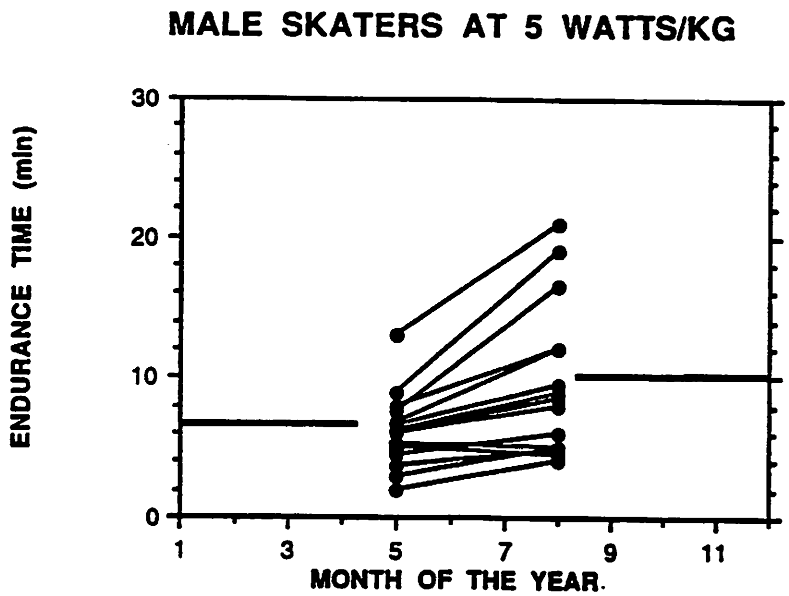
45


WINGATE ANAEROBIC TEST
y = 1.8891 + 0.14331x - 1.1460e-2x^2 R^2 = 0.625
1500 m Time (minutes)
2.4
2.2
2.0
1.8
7
8
9
10
11
12
13
14
15
POWER OUTPUT (Watts/kg)

46

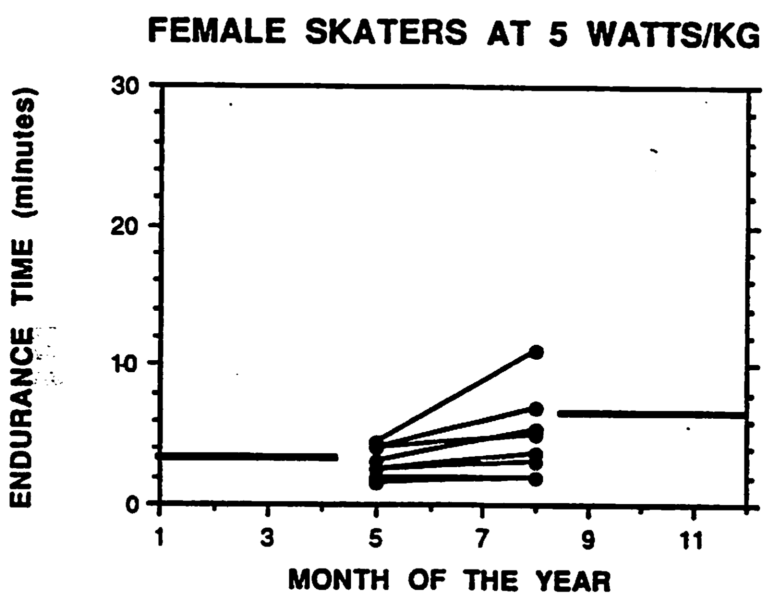

ENDURANCE TIME @ 5 WATTS/KG
MEN AND WOMEN
y = 2.3869 - 5.4280e-2x + 1.5258e-3x^2 R^2 = 0.679
1500 m TIME (minutes)
2.6
2.4
2.2
2.0
1.8
0
4
8
12
16
20
24
ENDURANCE TIME (minutes)

47



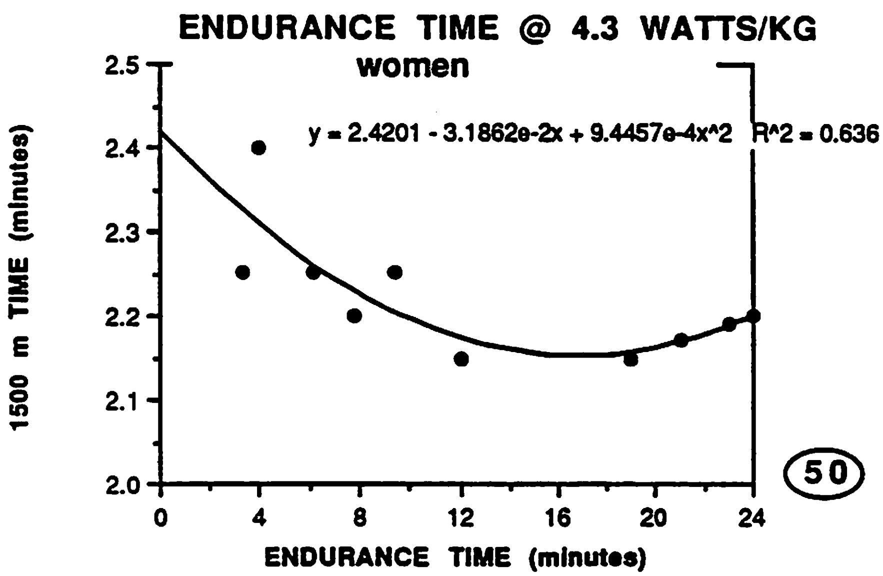
MALE SKATERS AT 5 WATTS/KG
ENDURANCE TIME (min)
30
20
10
0
1
3
5
7
9
11
MONTH OF THE YEAR

48

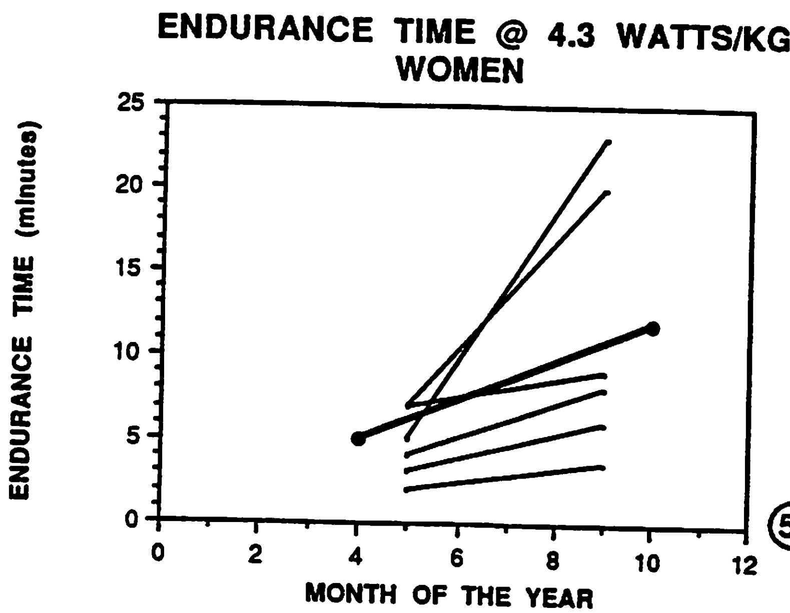


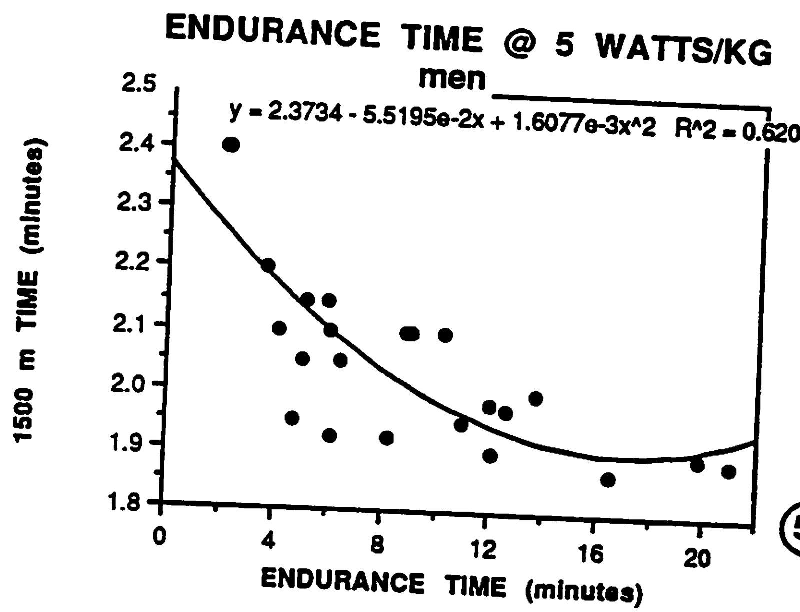
FEMALE SKATERS AT 5 WATTS/KG
ENDURANCE TIME (minutes)
30
20
10
0
1
3
5
7
9
11
MONTH OF THE YEAR

49


ENDURANCE TIME @ 4.3 WATTS/KG
women
y = 2.4201 - 3.1862e-2x + 9.4457e-4x^2 R^2 = 0.636
1500 m TIME (minutes)
2.5
2.4
2.3
2.2
2.1
2.0
0
4
8
12
16
20
24
ENDURANCE TIME (minutes)

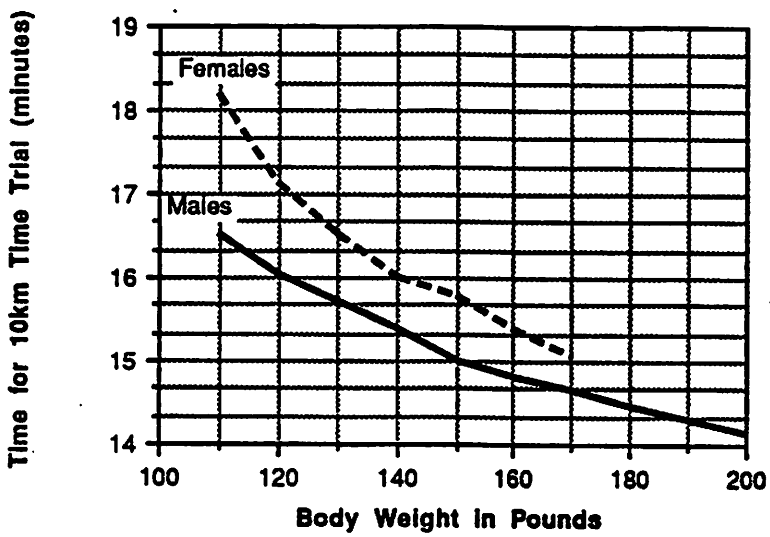
50


ENDURANCE TIME @ 4.3 WATTS/KG
WOMEN
ENDURANCE TIME (minutes)
0
5
10
15
20
25
0
2
4
6
8
10
12
MONTH OF THE YEAR

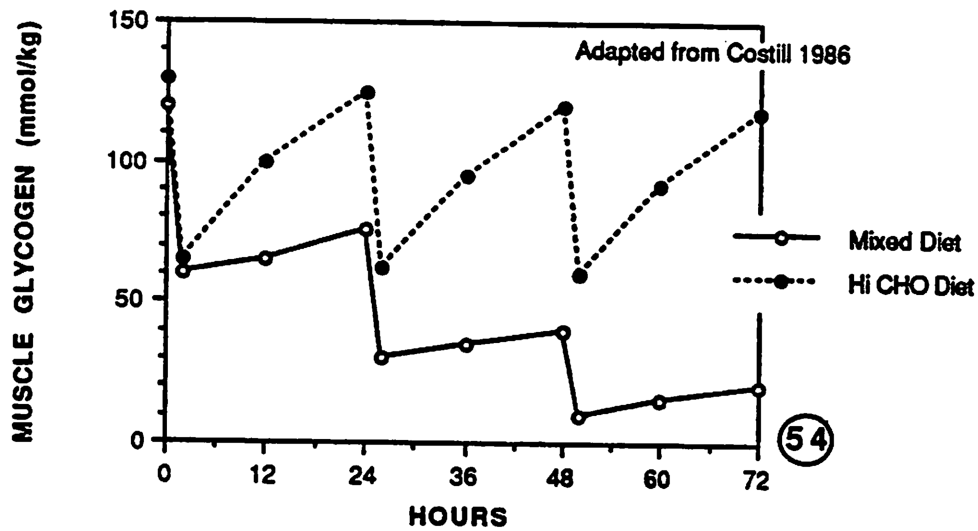

ENDURANCE TIME @ 5 WATTS/KG
men
y = 2.3734 - 5.5195e-2x + 1.6077e-3x^2 R^2 = 0.620
1500 m TIME (minutes)
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
0
4
8
12
16
20
ENDURANCE TIME (minutes)

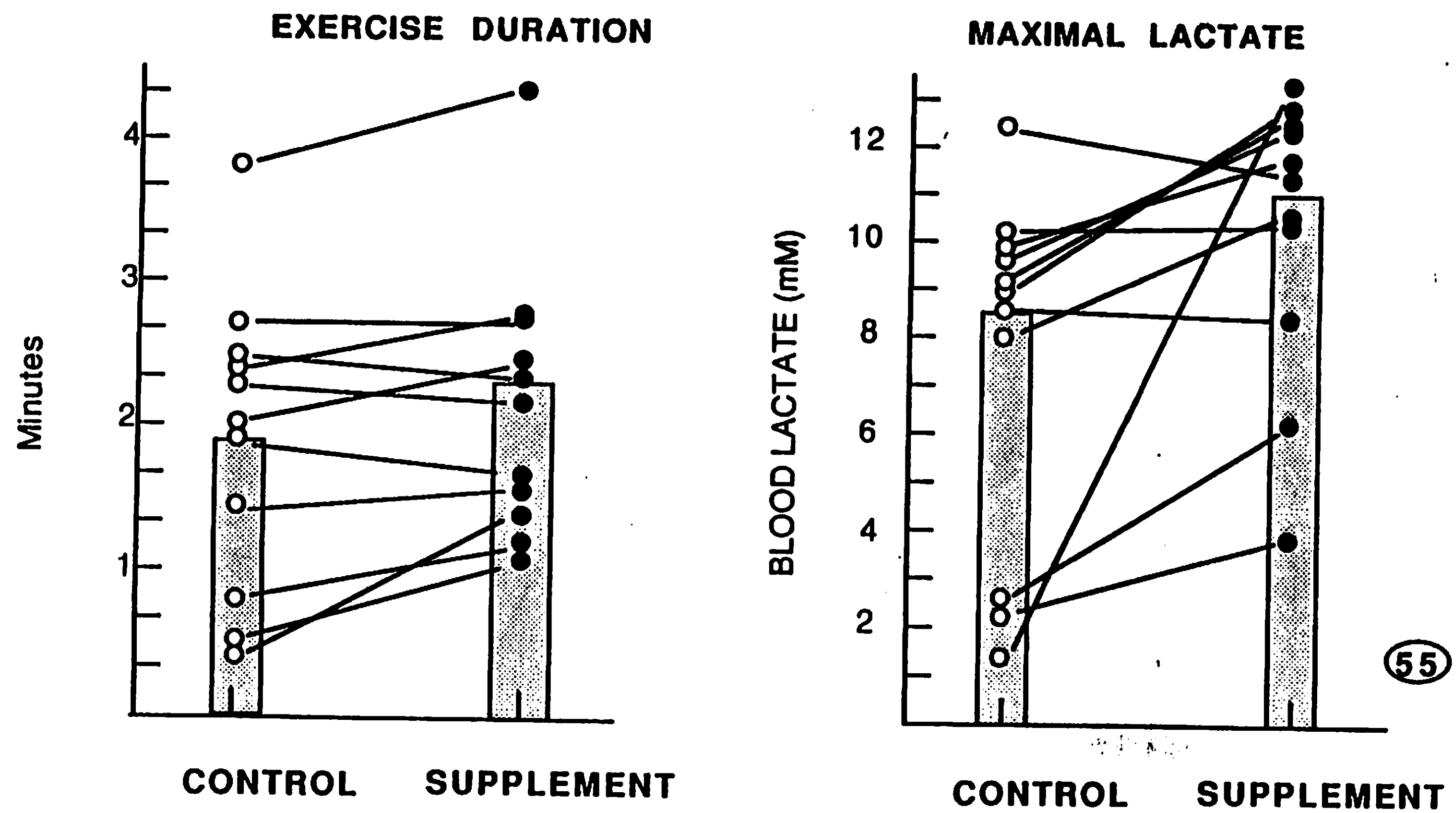
52

Skaters Cycling Fitness Test

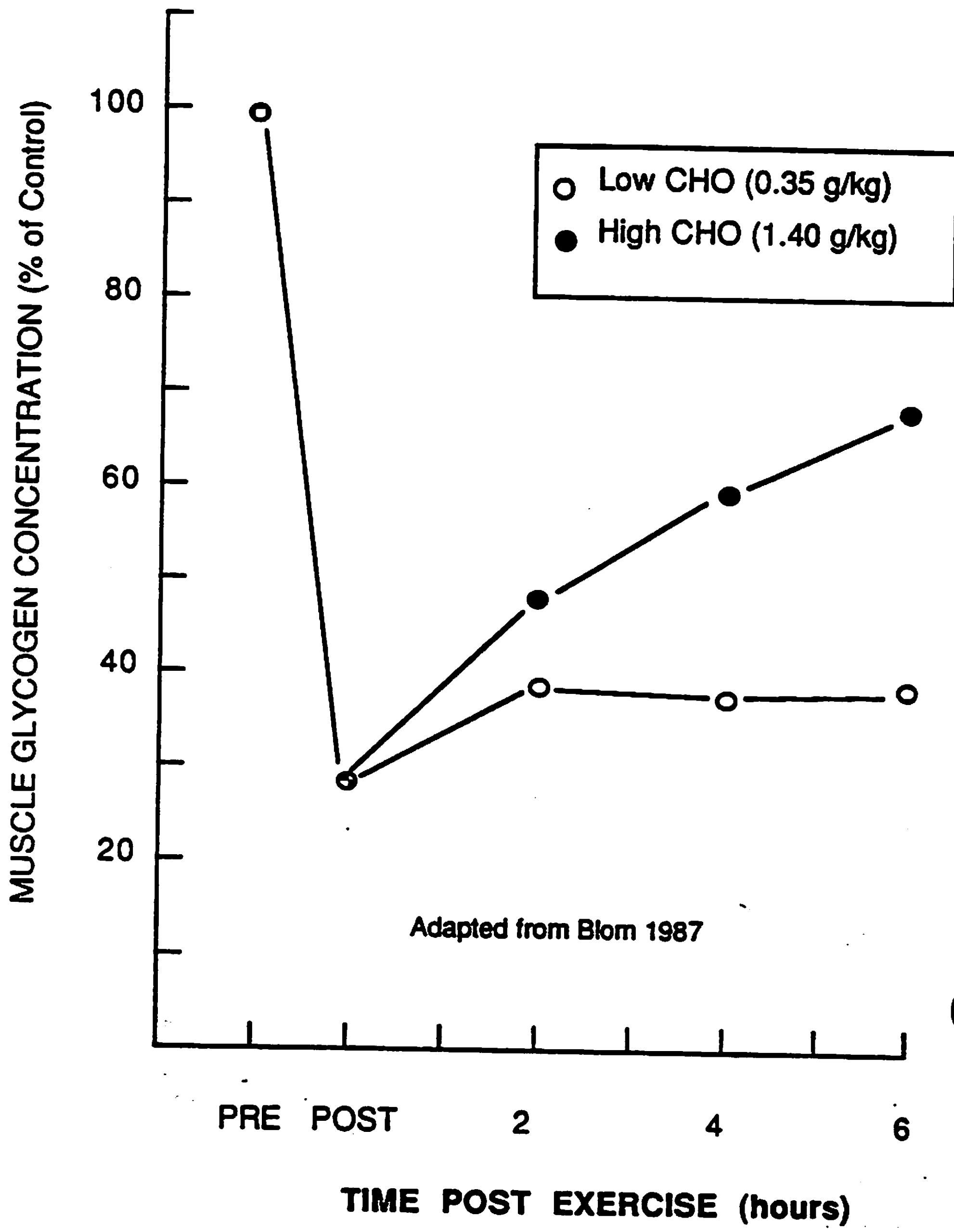


MUSCLE GLYCOGEN WITH HEAVY EXERCISE AND DIET

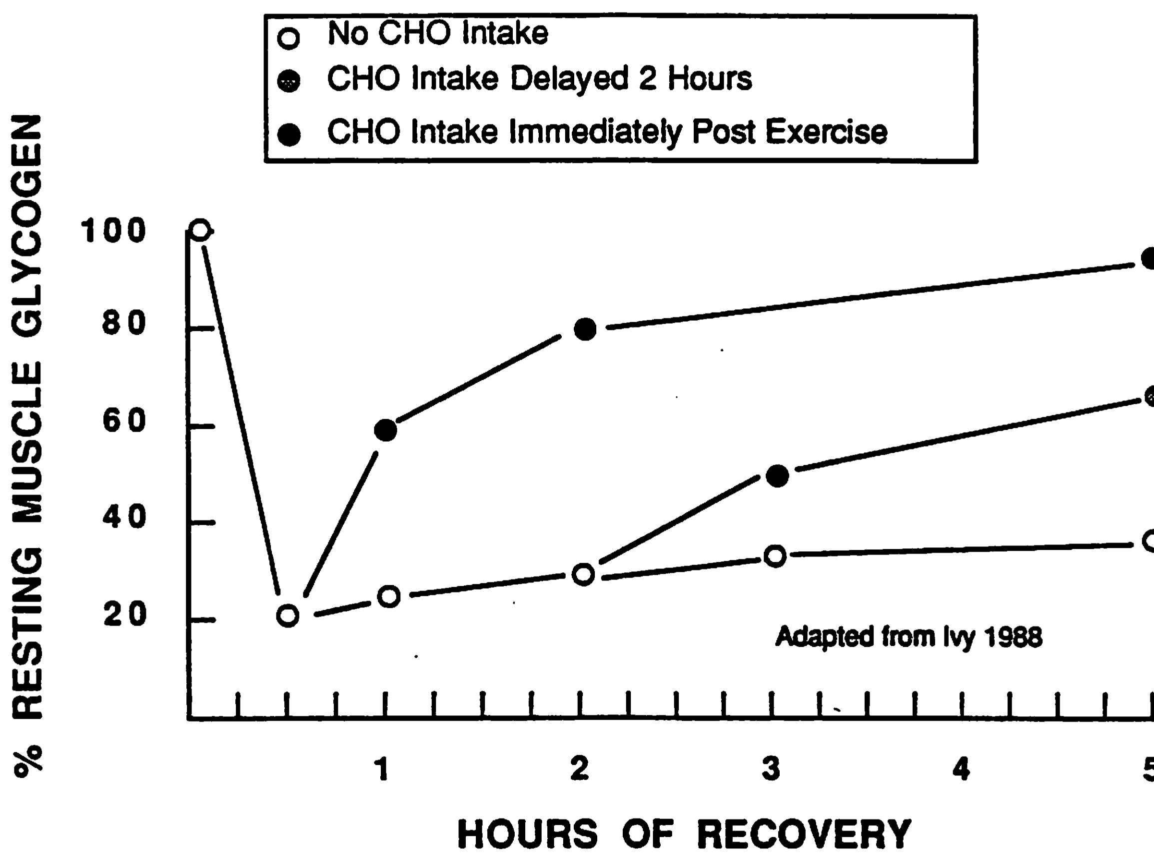




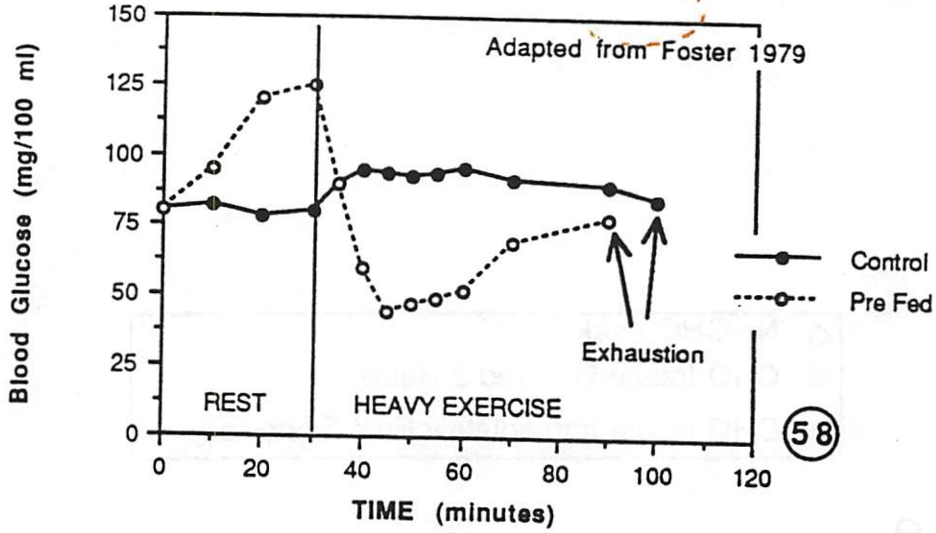
EXERCISE DURATION
Minutes
1
2
3
4
CONTROL
SUPPLEMENT
MAXIMAL LACTATE
BLOOD LACTATE (mM)
2
4
6
8
10
12
CONTROL
SUPPLEMENT



MUSCLE GLYCOGEN CONCENTRATION (% of Control)
100
80
60
40
20
Low CHO (0.35 g/kg)
High CHO (1.40 g/kg)
Adapted from Blom 1987
PRE
POST
2
4
6
TIME POST EXERCISE (hours)


No CHO Intake
CHO Intake Delayed 2 Hours
CHO Intake Immediately Post Exercise
% RESTING MUSCLE GLYCOGEN
100
80
60
40
20
1
2
3
4
5
HOURS OF RECOVERY
Adapted from Ivy 1988

PRE EXERCISE FEEDINGS, BLOOD GLUCOSE AND FATIGUE



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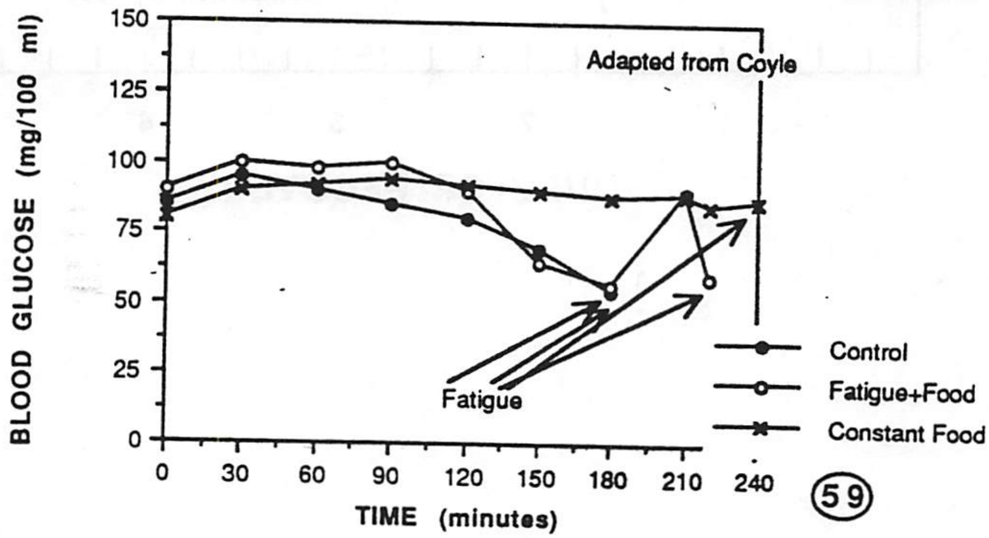
FEEDING EFFECTS ON BLOOD GLUCOSE AND FATIGUE



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