

Failing to Adapt to Training

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"If you are tired, you are not in shape; if you are not tired, you have not been working hard enough." Anonymous

Introduction

Successful adaptation to training is necessary to ensure better competitive performances. This adaptation is based on the athlete's physiological and psychological responses to four important training factors: type, frequency, duration and intensity of exercise and, unless these factors are managed carefully, they can lead to failing adaptation or overtraining syndrome. The coach must offer a special blend of these factors at critical periods during the training process in order to achieve improved training and competitive performances. This blend is especially difficult to manage for crews, as the boat is only as strong as its weakest link. So, in the process of training, one of your athletes may tolerate the work very well while another falters under the load.

Failing to adapt to training has some major physiological and psychological consequences, all of which lead to increasingly poorer training and competitive performances. It is difficult to design optimal training programs for everyone in the crew and, although some coaches employ a sound scientific approach in developing training programs, many still base their training programs on intuitive and empirical judgements with "more" and "harder" being the most important descriptive criteria. It is difficult to assess the relative impact of training on the athlete and there seem to be no specific preliminary symptoms to warn the athletes that they are failing to adapt. By the time failing adaptation has been recognized, it is usually too late to effectively reverse the condition and the athlete's only option is weeks or months of reduced training or complete rest; this could mean the end of high level competition for that year.

A critical aspect of failing adaptation is that it is often your most highly skilled and motivated athlete who is susceptible to failing adaptation. Athletes who are excessively aggressive, always trying to perform at their best, are more critical of themselves than others, have set extremely high standards, want to win at all costs, genuinely believe they are physically indestructible, and can't seem to get enough work, must be observed carefully by the coach and perhaps more strictly controlled.

Failing adaptation is difficult to define and even more difficult to measure and prevent. The following discussion will likely ask more questions about this controversial topic than provide answers.

Symptoms

Symptoms of failing to adapt to training vary among individuals but the most common general feeling is one of heaviness in the muscles. This is usually accompanied by a gradual deterioration in training and competitive performances.

It is difficult to distinguish between failing to adapt to training and chronic fatigue resulting from training. The day to day variations in the sensations of fatigue should not be confused with failing adaptation. Chronic fatigue can result from consecutive days or bouts of hard training or intense competition but can be relieved with a few days of easy training, no competition and a carbohydrate-rich diet. At present there are no clear signs or body alarm systems that indicate a failure to adapt to training, especially no early warning signals and as a result the process is often too far along to be reversed. Most symptoms are subjective and identifiable only after athletes have overextended themselves. Many rowers also attempt to conceal failing to adapt from the coach in fear of losing their seat in the boat although they may be aware that they are gradually seeing an erosion of their performance. This erosion may be difficult for the coach to evaluate since other crew members may unknowingly "cover up" for their poorly adapting teammate. A coach should also be especially aware of any athlete who suddenly begins to produce extraordinary training performances, as they may be most susceptible to a failure to adapt. Because of their excitement about these performances they often overextend by training at a greater than normal intensity and duration.

With the onset of failing adaptation, the athlete usually experiences a vicious cycle of trying to overcome the poor training and competitive performances by training harder or changing technique. These responses more often lead to even greater physical and physiological deterioration and psychological frustration. The athlete, at this point, is uncertain about his/her skill and, in many cases, loses confidence. In addition, increasing training effort or changing technique can lead to serious injuries that may prevent the athletes from ever competing up to their potential.

Specific Symptoms

Specific symptoms include the following:

Physical and Physiological

1. Excessive and unusual weight loss
2. Change in body composition; decrease in body fat
3. Decreased appetite
4. Local muscular tiredness and heaviness
5. Sleep disturbances
6. Elevated heart rate, blood pressure, and core temperature
7. Decrease in immune protection
8. Decrease in male and female sex hormones
9. Overworking

Psychological

1. Frustration
2. Loss of confidence
3. Wide mood swings
4. Uncertainty
5. Tentative
6. Irritable
7. Uncommunicative and quiet
8. Self pity
9. Tardiness and missing work-outs
10. Looking for excuses
11. Depression
12. Anxiety
13. Trying too hard
14. Inability to relax

Causes

Physiologists agree that there is no greater physical stress that a human must tolerate than exercise. A muscle fiber is unparalleled among living cells in its ability to increase its metabolism, by 1000 times if necessary. A normal response to a continued exercise stress is an improvement in the muscle fiber's response and all of its support systems, thus adapting to exercise and the desired result is better performance. A normal stimulus-response relationship would be:

1. Increase in Training
2. Increase in Physiological factors
3. Increase in Performance
4. Increase in Confidence (positive re-enforcement)

The process of training and its effects on performance can be compared with a theory of adaptation proposed by Selye in the 1950s. Selye proposed a General Adaptation Syndrome (GAS) for the purpose of attempting to explain the ability or inability to cope with a stress. He divided his GAS into three stages: Alarm Reaction (AR), Stage of Resistance (SR), and Stage of Exhaustion (SE). Selye's AR can be compared with the introduction of high intensity training (stress stimulus) and positive early physiological changes (good response to stress). As the training stimulus is continuously and increasingly applied and the body responds by improving performance then this successful response is analogous to Selye's SR. However, if the response to the training stimulus is failing adaptation then this failure represents SE and if this stage is reached then the problem is difficult or impossible to correct. In fact, the extreme of Selye's SE is death of the organism or structure. This abnormal response can be represented as follows:

1. Increased Training
2. Decreased Physiological factors
3. Decreased Performance
4. Decreased Confidence (negative re-enforcement)

Although the causes for deterioration in performance are not clear, it appears that the intensity of training can be a greater negative stress than either the duration or

frequency of training. There is also evidence to show that problems unrelated to training may be partially or wholly to blame for failing adaptation, among them, job and or school related, social, economic, or personal.

Several possible physiological and physical causes of failing adaptation have been suggested and among them are:

1. Rapid increase in training intensity and/or volume; it is suggested that less than one percent increase per week for intensity and 3-5 percent per week for volume be used.
2. Chronic damage to muscle cells; death of cells
3. Overload of immune system
4. Abnormal endocrine responses
5. Disruption of connective tissue; tendon and ligament destruction
6. Nutrient deficiency; vitamin, mineral, etc.
7. Depletion of energy sources; glycogen, fats
8. Red blood cell damage and destruction
9. Chronic dehydration; decrease in blood volume
10. Anorexia nervosa
11. Abnormal cardiac rhythms
12. Decreased liver function
13. Chronic elevation of core temperature

Possible psychological causes, like the physiological and physical causes listed above, are linked closely to the many symptoms listed previously. The continued erosion of confidence, overworking in response to ever-decreasing training and competitive performances, and constant frustration are among a few of the important psychological causes of failing adaptation.

Measurement for Failing Adaptation

Although several attempts have been made to measure failing adaptation, especially attempts at early diagnosis, thus far no accurate means are available to either predict its onset or even detect if it has already occurred. It is often difficult to differentiate between what may be abnormal physiological responses related to a failure to adapt or simply normal responses to heavy training. Scientific studies describing failing adaptation are sparse because of the difficulty in isolating and measuring specific factors associated with this phenomenon. It is extremely difficult to control and manage such studies. However, based on the limited research and the many observations by coaches and athletes over the years, the following seem the most promising of possible measurements:

Measurements used previously:

1. Resting heart rate and chronic increases in blood pressure
2. Cardiac arrhythmias (changes in heart rhythm)
3. Increase in white blood cells; increase in eosinophil levels
4. Increase in cortisol levels
5. Chronic hypoglycemia
6. Decrease in muscular power and VO₂ Max
7. Decrease in muscle glycogen
8. Decreases in testosterone (male) and estradiol (female) or disturbances in free testosterone and bound testosterone; decrease in Tf/C

9. Increased lactic acid for standard submaximal exercise

Measurements that may have potential worth:

1. Body composition; abnormal decreases in body fat and lean body mass (LBM) and change in fat/LBM ratio
2. Chronic elevation in core temperature
3. Abnormal liver function tests; increases in SGOT and SGPT
4. Changes in endorphin levels
5. Decreases in hemoglobin; chronic anemia ("athlete's anemia"); disturbances in erythropoietin
6. Volume of Rapid Eye Movement sleep
7. Chronic decrease in blood volume
8. Chronic elevation of skeletal muscle enzymes

The most attractive factors for possible investigation are blood volume, body composition, muscle enzymes, core temperature, and red blood cell status, most of which are closely linked physiologically.

I am convinced that periodic submaximal ergometer testing may prove beneficial. Athletes should be tested frequently during the periods of high intensity or high volume training using rowing ergometry and power outputs ranging from 60 to 80 percent of maximum. Measurements of submaximal heart rate, VO_2 , lactic acid, O_2 deficit, and O_2 debt, and along with some of the other specific measurements listed previously, may prove to be useful in predicting and detecting failing adaptation. We have developed a test based on three consecutive submaximal efforts on a rowing ergometer that provides useful data concerning an athlete's specific physiological responses to training periodicity. In addition to measuring heart rate and lactate responses during and following 60, 70 and 80 percent of a mean maximal power output of the group, other physiological factors described in this measurement section could also be evaluated. It is also important to conduct most of these measurements during resting or recovery conditions without the immediate effects of exercise as examination of possible failing adaptation factors could be masked by the acute effects of a training session.

Prevention and Treatment of Failing Adaptation

Since it is difficult to identify any clear preliminary or early warning signs of failing adaptation, it is equally difficult to prevent it. Any coach and athlete would, of course, prefer not to see conditions develop where, no matter what the training strategy may be, performance continues to decrease. Some coaches suggest that there is no such phenomenon as failing to adapt to training but instead it is simply the fault of the athlete. In other words, it may be an inherent quality or qualities of the athlete that prevent adaptation and thus those failing athletes do not have the physiological and psychological capacities to adapt and thrive on a prescribed systematic training and racing program. The coach and athlete must also give careful attention to recovery or rest periods; they often forget that the length of these periods is equally as important as the intensity of the specific workout or series of workouts in the determination of overall training intensity. The length of recovery and rest periods are often overlooked and it may be that the insertion of a longer than planned rest or recovery period at a critical time in the high duration or intensity portion of training may help eliminate failing adaptation. It may also be

necessary to modify training sessions when athletes appear not to respond well to the duration and/or intensity of work.

Although some of the measurements discussed earlier may aid in helping to predict or reveal failing adaptation, the most effective measure is the coach's knowledge of athletes and the self-awareness of the athletes themselves. Not only should coaches and athletes record such daily entries in training diaries as distances, stroke rates, times, total volume, number of hard strokes, heart rates, lactates, etc., but more importantly both coach and athlete should carefully and immediately after each training session record their subjective feelings about the work-out; this procedure should also be used for the major training phases or periods. I would suggest that these observations of coaches and athletes be constantly compared so that a continuous line of communication be maintained between coach and athlete comparing how the coach views the responses of the athletes and how the athletes themselves feel; a simple rate of perceived exertion scale could be used.

I would strongly recommend that the coach and scientist combine their efforts to seek ways of predicting failing adaptation. I believe the most promising areas of physiological research are local muscle changes, "athlete's anemia" and chronic dehydration, increased core temperature, and lowered blood volume, the latter factor being the most important. However, the scientist cannot be with the athlete at every training session and thus it will ultimately be the coach who must find better methods of predicting and detecting failing adaptation.

Although the causes of failing adaptation are not clear and this problem more likely results from a combination of some or all of the factors discussed in this presentation, it is probable that the intensity, speed or rate, of training is a more important stress than volume of training. Diminishing the prospects of failing adaptation results from a significant reduction in training intensity or complete rest. Many coaches believe that failing adaptation symptoms can be reduced or eliminated by a few days of light training when it would be best for the athlete to rest completely for 2 to 3 days, followed by 3 to 4 days of some form of easy cross training. It may be recommended that the athlete seek some form of counseling especially if the problem is non-sport related such as poor nutrition, or an academic, economic or social problem.

Prevention is obviously preferable to having to cure failing adaptation. It is no secret that in order to minimize the risk of failing adaptation it is best to use a periodic training program where easy, moderate, and hard training periods are alternated. As a rule, one or two days of intense training should be followed by an equal number or more of easy training days. This should also apply to weekly planning and 1 to 2 weeks of hard training should be followed by a week of easy work.

In summary, I believe there is only a subtle difference between what are normal responses to heavy training and the abnormal responses associated with failing adaptation, in fact, so finite that it may not be possible to accurately measure, detect, and prevent. However, this is such a major problem that the coach and scientist must continue to work closely together to discover possible early warning signs and thus still have time to reverse this debilitating condition.

References

1. Brown, R.L., E.C. Frederick, H.L. Falsetti, E.R. Burke, and A.J. Ryan. 1983. Overtraining of athletes. A round table. *Phys. Sptsmed.*, 11: 93-110.
2. Callister, R., R.J. Callister, S.J. Fleck, and G.A. Dudley. 1990. Physiological and performance responses to overtraining in elite judo athletes. *Med. Sci. Spts. Exerc.*, 22(6): 816-824.
3. Dragan, I. Overtraining. In: *Basic Book of Sports Medicine*. Lausanne: International Olympic Committee, 1978, pp. 305-310.
4. Dressendorfer, R.H., and C.E. Wade. 1983. The muscular overuse syndrome in long-distance runners. *Phys. Sptsmed.*, 11: 116-130.
5. Dressendorfer, R.H., C.E. Wade, and J.H. Scaff. 1985. Increased morning heart rate in runners: a valid sign of overtraining? *Phys. Sptsmed.*, 13: 77-86.
6. Hagerman, F.C., R.S. Hikida, R.S. Staron, W.M. Sherman, and D.L. Costill. 1984. Muscle damage in marathon runners. *Phys. Sptsmed.*, 12(11): 39-48.
7. Hakkinen, K., A. Pakarinen, M. Alen, H. Kauhanen, and P.V. Komi. 1987. Relationships between training volume, physical performance capacity and serum hormone concentrations during prolonged training in elite weight lifters. *Int. J. Spts. Med.*, 8: 61-65.
8. Hanne-Papero, M. 1983. Overtraining in athletes. *Oly. Rev.*, 194: 829-832.
9. Hikida, R.S., R.S. Staron, F.C. Hagerman, W.M. Sherman, and D.L. Costill. 1983. Muscle fiber necrosis associated with human marathon runners. *J. Neurol. Sci.*, 59: 185-203.
10. Kereszty, A. Overtraining. In: *Encyclopedia of Sports Sciences and Medicine*. L.A. Larson, and D.E. Hermann (Eds.) New York: Macmillan Publishing Co., 1971, pp. 218-222.
11. Kirkendall, D.T. 1990. Mechanisms of peripheral fatigue. *Med. Sci. Spts. Exerc.*, 22(4): 444-449.
12. Kuipers, H., and H.A. Keizer. 1988. Overtraining in elite athletes. *Spts. Med.*, 6: 79-92.
13. Mellerowicz, H., and D.K. Barron. Overtraining. In: *Encyclopedia of Sports Sciences and Medicine*. L.A. Larson and D.E. Hermann (Eds.) New York: Macmillan Publishing Co., 1971, pp. 1310-1312.
14. Morgan, W.P., D.R. Brown, J.S. Raglin, P.J. O'Connor, and K.A. Elickson. 1987. Psychological monitoring of overtraining and staleness. *Br. J. Spts. Med.*, 21: 107-114.
15. Nadel, E.R. 1985. Physiological adaptations to aerobic training. *Am. Scientist*, 73: 334-343.
16. Nilsson, S. Overtraining. In: *Scandinavian Conference in Sports Medicine, 2, Oslo 1986. An Update on Sports Medicine*, S. Haehlum, S. Nilsson, and P. Renstrom (Eds.) Strommen: Syntex, 1987, pp. 97-104.
17. Selye, H. 1956. *The Stress of Life*. New York: McGraw Hill.
18. Wilmore, J. H., and D. L. Costill. 1988. *Training for Sport and Activity, the Physiological Basis of the Conditioning Process*, Dubuque, IA: Wm. C. Brown Publishers.

Rowing in Hot Weather

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As we move into spring and summer, athletes will be exposed to hot weather and its effects. Dehydration, one of those effects, can lead to some very serious consequences, most notably heat cramps, heat syncope, heat exhaustion, and heat stroke. These conditions can progress rapidly from cramps to a severe stroke in a matter of minutes. Since an athlete's intense concentration during training and competition may cause him to ignore or misinterpret any of the usual warning signs, coaches must be conscious of the effects of hot weather and be prepared to identify signs of heat-produced injury.

Thermal Injury

Athletes are often so focused during training and competition that they don't recognize the symptoms of potential heat problems immediately. They are also prone to overexerting themselves. Rowers should be advised of the early signs of heat injury which may include dizziness, co-ordination impairment, visual disturbances, loss of balance, excessive (or lack of) sweating, chills, nausea, headache, and loss of consciousness. This process can rapidly evolve into a dangerous situation; some emergency room physicians consider heat injury as the ultimate physical insult to the body. Prevention is the most important consideration. The specific heat disorders, in order of severity, are as follows:

1. *Heat Cramps* - This disorder is characterized by uncontrollable muscle spasms, especially in the legs. Although the condition is usually associated with unacclimatized athletes, it frequently occurs in adapted athletes as well.
2. *Heat Syncope* - This condition is characterized by weakness and fatigue, blurred vision, paleness, decreased blood pressure, syncope (loss of consciousness), and elevated skin and core body temperatures. It can affect the acclimatized rower in excessively hot weather but usually occurs in the unacclimatized athlete.
3. *Heat Exhaustion* - This problem can occur as a result of severe water or salt depletion or both. Heat exhaustion due to water depletion is acute and is characterized by reduced sweating, "cotton-mouth," increased skin and body core temperatures, muscular weakness, and loss of co-ordination. Heat exhaustion due to salt depletion can cause headache, dizziness, fatigue, nausea, vomiting, diarrhea and syncope. This condition has a slow response time usually taking three to five days to develop. Both conditions can occur in either the acclimatized or unacclimatized athlete.
4. *Heat Stroke* - The most serious condition, heat stroke is a life-threatening situation. The entire thermal regulating system is seriously compromised. Skin and core temperatures reach their highest levels, with core temperature climbing as high as 40° C (105° F). Other symptoms include muscle

weakness, involuntary muscle contractions, vomiting, diarrhea, rapid and shallow heartbeat, hallucinations, convulsions, and finally coma.

Heat Regulation During Exercise

Moderate exercise by untrained and unacclimatized athletes can be performed safely in temperatures ranging from 10-30°C (50-85°F), but high relative humidity can present a danger at temperatures as low as 21°C (70°F). When environmental temperature and humidity reach very high levels, it is not possible to adequately lose the heat produced during exercise.

Muscle contraction during exercise produces a large amount of heat, and therefore body temperature rises. This rise in body temperature triggers an increase in perspiration and blood flow to the skin. But exercise, even of moderate intensity, requires blood flow to be directed to the working muscles. Shunting blood to the muscles at the expense of the skin in hot weather can cause great harm to athletes; they will not be able to adequately dissipate the extreme heat build-up. Blood simply cannot be in two important places at once - the muscles always win. An athlete's only safe choice under these circumstances is to reduce the intensity of exercise, thereby lowering heat production and allowing more blood to reach the skin.

Heat Adaptation

If an important competitive event is to be conducted in an excessively hot and humid environment, research shows that athletes may acclimatize themselves by training at a light to moderate level. With proper heat adaptation and proper training, rowers can safely increase the intensity and duration of exercise in warmer environments.

For example, coaches should use a progressive training program of gradually increasing intensity performed in the heat for 10 to 15 days (see **Training in Hot Weather** below). The program should begin with 20 to 30 minutes of light to moderate work and end with as much as two to three hours of work (or two workouts) on day 15. By following this regimen, athletes can exercise longer and at a higher intensity, although maximal performances will be difficult given the harsh environment.

Research also shows that heat acclimatization is best when hot weather conditions and training are combined; merely resting in the heat produces very little tolerance. Increases in metabolic rate and compatible heat production during training sometimes cause core temperatures to increase to as high as 40°C (105°F). The increase in core temperature [not to dangerous levels of 39-40°C (103-105°F)] is necessary because it promotes the important circulatory and perspiration adjustments that must occur in acclimatization.

Successful heat adaptation causes the following adjustments: 1.) Lower resting core temperature; 2.) lower skin temperature, 3.) decreased exercise heart rate and metabolism, and 4.) increased sweating and evaporative cooling.

Training in Hot Weather

Athletes who typically train and compete in cool weather and low humidity can be better prepared for hot weather competition by following a few recommendations. If they cannot arrive at the site 10 to 15 days prior to competition, hot weather conditions can be simulated by training in excess clothing. Nylon or rubberized suits are not recommended. The athletes should attempt to lose one to three percent of their body weights through water loss (sweating) daily, then replace lost fluids as suggested.

Also, weigh-ins should be accurately monitored before and after practice. The body's water balance and energy stores must be carefully controlled during the days before competition (part of tapering process) and again immediately before competition. Although specific recommendations are difficult to make because individuals acclimatize to the heat at different rates, volume and intensity of workouts in the heat should be reduced by as much as 10 to 40 percent depending on the severity of the heat. For example, if a tapering workout of 1 x 2000m and 1 x 1000m at maximal capacity is planned, following 3000m of warm-up and ending with 2000m of warm-down - both at about 70 percent of maximal capacity - then it might be wise to reduce the 2000m to 1500m and the 1000m to 500m. Increase the rest interval between the two pieces.

The warm-up and warm-down may also be reduced in volume and intensity. For example, a 2000m warm-up and a 1000m warm-down at 60 percent of maximal capacity might be more appropriate. A few starts, a little technique work, and a minimum number of hard strokes should also be included. These methods should also apply to pre- and post-competition as well. Experimentation with the crew's adaptation to heat must not be delayed until the tapering process or until race day. Again, begin the routine of hot weather rowing, either actual or simulated, at least 10 to 15 days before competition.

Dehydration and Rehydration

Among all animals, humans are least able to respond to excessive water loss from the body. Careful planning for rehydration during hot weather training and competition is essential to ensure optimal performances. Although sweating helps to cool the body, it also removes essential elements such as water and sodium from the body. Because water serves as the great chemical solvent in the muscle cell, body water lost as sweat must be replaced as frequently as possible to avoid dehydration and the accompanying heat injuries described earlier. It is not uncommon for rowers to lose as much as two to four percent of their total body weight through water loss in a single workout, which can adversely impact muscular function. In addition, the reduction in circulating blood volume lowers the amount of blood in the heart and decreases the volume of blood the heart can deliver with each beat (decrease in cardiac output). Significant decreases in cellular water can slow metabolic reactions. In order to maintain blood pressure and cardiac output under these conditions, heart rate must increase.

An athlete's thirst mechanism is not very sensitive when large amounts of water are lost through sweating. Athletes who rely on the body's natural response to drink will remain dehydrated. Therefore, the athlete must drink more than what his thirst stimulus dictates. A liter-size squeeze bottle should be standard equipment for any rower during hot weather. An athlete should drink small amounts at frequent

intervals during a training session [e.g., 120 to 177 ml (four to six fl. oz.) every 10 to 15 minutes]. In addition, athletes should drink frequently and generously between workouts and ingest four to five glasses of fluid during the two hours preceding training; this recommendation can also be applied before competition. Athletes should drink more fluid than normal two to three days prior to competition.

Fluid Replacement

All hot weather experts agree that fluid loss must be replaced, but there is wide disagreement concerning the make up of the fluid replacement. Once an athlete is acclimatized to hot weather, sweat usually will have nearly the same concentration of electrolytes (sodium, chloride, potassium, etc.) as the body fluids. However, recent evidence has shown that rehydration with plain water tends to dilute the blood and causes an increase in urine production, thus leading to further dehydration. Also, intake of plain water seems to inhibit the thirst mechanism, which, as reported earlier, is already sluggish in its response to large water losses. Adding electrolytes, specifically sodium, to fluid will allow more water to be retained and at the same time stimulate the thirst mechanism.

Although water is the most important ingredient, some experts recommend that the best combination for replacement drinks contains both sodium and glucose. If blood and muscle sugars (glucose and glycogen) are not maintained, training performances will suffer. The optimum range of carbohydrate concentration in replacement drinks should contain two and one half percent to eight percent, depending upon 1) time of day, 2) intensity of the workout, 3) temperature and humidity, 4) type of clothing worn, and 5) type of drink. Most successful commercial sport drinks contain an optimal mixture of electrolytes and carbohydrates. Also, contrary to popular belief, cold drinks do not retard emptying of stomach from the stomach or cause stomach cramps. Rather, cold drinks appear to move a little more quickly through the gut and also permit more rapid internal cooling.

Most athletes prefer to drink plain water during training and sport drinks between workouts, because exclusive use of a commercial sport drink for all fluid replacement is not economically feasible. Substituting salted water for the sport drink is less expensive and still effective. Simply dissolve one to two grams of salt in a liter of water; this mixture will not have a salty taste. A mixture of lemonade concentrate (355 ml or 12 oz.), water (1,770 ml or 60 fl. oz.), and four grams of salt can serve as a replacement drink as well. Avoid salt tablets under any circumstances because large amounts of salt can irritate the stomach and induce vomiting and diarrhea.

Since muscle glycogen restoration occurs more quickly if one increases carbohydrate intake immediately after exercise, an athlete may have a sport drink containing sodium and carbohydrate at this time. Again, emphasize rehydration at meals and snacks where water, sport drinks, fruit juices, and carbonated and non-carbonated beverages can be consumed. Avoid drinks containing caffeine or alcohol, which further stimulate urine production. [NOTE: Although the super hydrated athlete suffers no performance impairment, it is important not to train or compete on a full stomach.]

Guidelines for Training and Competition in Hot Weather

1. Schedule training and competition during the coolest parts of the day.
2. Plan shorter and less intense workouts at the scheduled race time, especially if competition is set at a time when heat and humidity is predicted to be extreme.
3. Provide at least 48 hours of recovery (light workouts) between high intensity workouts.
4. Allow at least 15 days for adequate acclimatization if athletes will be competing in the heat.
5. Wear light-colored, loose fitting clothing, preferably of cotton or a cotton-blend fabric with a loose weave design. Do not wear wet clothing because it reduces heat loss.
6. Do not restrict fluids before, during, or after training or competition.
7. Weigh in without clothes before and after each workout to determine extent of water loss. For each kg (two pounds) of body weight lost during a workout, drink at least one liter of fluid, excluding the first kg (e.g., 2 kg lost=1 liter replacement, 3 kg lost=2 liters replacement). Usually athletes with a two percent deficit of water weight before the next practice should be excused from that practice.
8. Note urine color and frequency of urination during hot weather - a lighter urine color and more frequent trips to the toilet indicate adequate rehydration.
9. Emphasize plain water during actual training and sport drinks composed of sodium mixed with two and one half to eight percent glucose or sucrose between workouts (for very long workouts, two hours or more, a six to eight percent concentration is recommended).
10. Drink at least one glass of fluid every 10 to 15 minutes during a workout, and four to five glasses during the two hours preceding a workout or competition.
11. If intense sun exposure is unavoidable during training and/or competition, wear a hat and sunglasses.
12. If symptoms of heat intolerance become evident, suspend exercise and seek medical help immediately.

References

1. Costill, D.L., and K.E. Sparks. Rapid fluid replacement following dehydration. *J. Appl. Physiol.* 34:36-43, 1973.
2. Convertino, V.A., J.E. Greenleaf, and E.M. Bernauer. Role of thermal and exercise factors in the mechanism of hypervolemia. *J. Appl. Physiol.* 48:657-664, 1980.
3. Coyle, E.F. A.G. Coggan, M.K. Hemmert, and J.L. Ivy. Muscle glycogen utilization during prolonged strenuous exercise when fed carbohydrate. *J. Appl. Physiol.* 61: 165-172, 1986.

4. Fox, E.L., R.W. Bowers, and M.L. Foss. The physiological basis of physical education and athletics. 4th edition, Saunders College Publishing, Philadelphia, 1988.
5. Fortney, S.M., C.B. Wenger, J.R. Bove, E.R. Nadel. Effect of blood volume on forearm venous and cardiac stroke volumes during exercise. *J. Appl. Physiol.* 55: 884-890, 1983.
6. Gisolfi, C.V. and C.B. Wenger. Temperature regulation during exercise: Old concepts, new ideas. In Terjung, R.;J. (ed), *Exercise and Sport Sciences Reviews*. Vol. 12. The Collamore Press, Lexington, 1984.
7. Gisolfi, C.V. (ed). Symposium on the thermal effects of exercise in the heat. *Med. Sci. Sports.* 11 (1): 30-71, 1979.
8. Morimoto, T., K. Miki, H. Nose, S. Yamada, K. Hirakawa, and C. Matsubara. Changes in body fluid and its composition during heavy sweating and effect of fluid and electrolyte replacement. *Jpn. J. Biometer.* 18: 31-39, 1981.
9. Nadel, E.R., S.M. Forney, and C.B. Wenger. Effect of hydration state on circulatory and thermal regulations. *J. Appl. Physiol.* 49: 715-721, 1980.
10. Nose, H., G.W. Mack, T. Yawata, and T. Morimoto. Recovery of blood volume and osmolarity after thermal dehydration in rats. *Am. J. Physiol.* 251: 492-498, 1986.
11. Nose, H., G.W. Mack, X. Shi, and E.R. Nadel. Role of osmolarity and plasma volume during rehydration in humans. *J. Appl. Physiol.*, in press.
12. Rowell, L.B. Human cardiovascular adjustment to exercise and thermal stress. *Physiol. Rev.* 45 (1): 75-159, 1974.

Training in Extreme Environments - The Need for Rehydration

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The capacity for exercise performance is reduced when the environmental conditions are less than optimal, but extremes of environmental temperature or barometric pressure are often encountered in situations where hard exercise has to be performed. This presentation will focus on the problems associated with dehydration and with optimisation of fluid intake to maximise exercise performance, since these are the problems most often encountered during training and competition.

The main causes of fatigue in prolonged exercise are normally depletion of the body's energy stores or by disturbances of temperature regulation and fluid balance. The importance of dehydration is clearly demonstrated by the reduced capacity to perform exercise in the heat and by the relatively high incidence of heat illness encountered during major competitions held in hot climates: athletes, however, commonly ignore the need to replace fluids lost during exercise. The need for rehydration is more often recognised by endurance athletes, but dehydration also has an adverse effect on high-intensity short-duration exercise.

Fluid ingestion during exercise and during the recovery period has the twin aims of providing a source of carbohydrate fuel to supplement the body's limited stores and of supplying water and electrolytes to replace the losses incurred by sweating. Increasing the carbohydrate content of drinks will increase the amount of fuel which can be supplied, but will tend to decrease the rate at which water can be made available; where provision of water is the first priority, the carbohydrate content of drinks will be low, thus restricting the rate at which substrate is provided. The composition of drinks to be taken will thus be influenced by the relative importance of the need to supply fuel and water; this in turn depends on the intensity and duration of the exercise task, on the ambient temperature and humidity, and on the physiological and biochemical characteristics of the individual athlete.

Carbohydrate ingested during exercise appears to be readily available as a fuel for the working muscles, at least when the exercise intensity does not exceed 70-75% of maximum oxygen uptake. Carbohydrate-containing solutions appear to be more effective in improving performance than plain water, and solutions of glucose, sucrose and glucose polymers all produce similar results.

Water and electrolytes are lost from the body in sweat; although the composition of sweat is rather variable, it is invariably hypotonic with respect to plasma. The normal result of sweat loss is thus to increase the plasma concentration of all the major electrolytes. Sweat rate is determined primarily by the metabolic rate and the environmental temperature and humidity, but varies greatly between individuals exercising under the same conditions. The sweat rate may exceed the maximum rate of gastric emptying of ingested fluids; most athletes consume far

less fluid during exercise than they are capable of assimilating, and some degree of dehydration is commonly observed. Excessive replacement of sweat loss with plain water or fluids with a low sodium content may result in hyponatraemia, but this is uncommon and athletes should be encouraged to drink in excess of the need dictated by thirst.

Rehydration after exercise is particularly important in training where exercise may have to be repeated after a rather short interval. Sodium replacement is essential for post-exercise rehydration, and this may be the major benefit of the small amounts of sodium added to commercial sports drinks. The optimum frequency, volume and composition of drinks will vary widely depending on the intensity and duration of the exercise, the environmental conditions and the physiology of the individual, and it is thus difficult to make specific recommendations that will suit all sportsmen and women. The athlete must determine by trial and error the most suitable regimen, and should experiment in training to find a rehydration fluid which is both effective and palatable. The body cannot adapt to increase its tolerance to dehydration, but rather dehydration during training will have the effect of decreasing the training load that can be sustained and thus reduce the effectiveness of the training programme.

Fluid Replacement

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Many factors will affect the sportsman's need for fluid replacement during training and competition. The composition of the fluid, as well as the volume and frequency of drinks, which will confer the greatest benefit during exercise will depend very much on individual circumstances. As with most physiological variables, there is a large inter-individual variability in the rates of fluid loss during exercise under standardised conditions and also in the rates of gastric emptying and intestinal absorption of any ingested beverage. Marathon runners competing under the same conditions and finishing in the same time may lose as little as 1% or as much as 5% of bodyweight, even though their fluid intake during the race is the same (Maughan 1985). Under more controlled conditions, Greenhaff and Clough (1989) found that sweat rate during 1 hour of exercise at a workload of 70% VO_2 max and an ambient temperature of 23°C ranged from 426 to 1665 g/h: the sweat rate in this situation is largely determined by the metabolic rate, and is related to fitness and bodyweight. It would seem logical that the need for fluid (water) replacement is greater in the individual who sweats profusely, and any guidelines as to the rate of fluid ingestion and the composition of fluids to be taken, must be viewed with caution when applied to the individual athlete. Sweat rate during activities such as running can be predicted from estimates of the energy cost of running, as used by Barr and Costill (1989), but these do not explain the variation which is observed between individuals. A more reliable method might be for the individual to measure bodyweight before and after training or simulated competition and to estimate sweat loss from the change in bodyweight.

Many individuals and organisations have issued recommendations as to the most appropriate fluid replacement regimens (e.g., American College of Sports Medicine 1975, 1984; Olsson & Saltin 1971). Olsson and Saltin (1971) recommended 100 to 300 ml of a 5 to 10% sugar solution every 10 to 15 minutes during exercise; they also suggested that the temperature of ingested fluids should be 25°C. At the extreme ends of this range, this would give an intake each hour of 400 to 1800 ml of liquid and 20 to 180 g of sugar. In 1975 the American College of Sports Medicine published a Position Statement on the prevention of heat injuries during distance running, in which an intake of 400 to 500 ml of fluid 10 to 15 minutes before exercise was recommended. Although no figures were given, it was also suggested that runners ingest fluids frequently during competition and that the sugar and electrolyte content of drinks should be low (2.5% glucose and 10 mmol/L sodium, respectively) so as not to delay gastric emptying. A revised version of these guidelines (American College of Sports Medicine 1984) continued to recommend hyperhydration prior to exercise by the ingestion of 400 to 600 ml of cold water 15 to 20 minutes before the event. The recommendations as to intake during a race were more specific than previously: cool water was stated to be the optimum fluid, and an intake of 100 to 200 ml every 2 to 3 km was suggested, giving a total intake of 1400 to 4200 ml at the extremes. Again, taking these extreme values, it is unlikely that the elite runners could tolerate a rate of intake of about 2 L/h, and equally unlikely that an intake of 300 ml/h would be adequate for the slowest competitors except when the ambient temperature was low.

Exercise Intensity and Duration

The rate of metabolic heat production during exercise is dependent on the exercise intensity and the body mass; in activities such as running or cycling this is a direct function of speed. The rate of rise of body temperature in the early stages of exercise and the steady state level which is eventually reached are both proportional to the metabolic rate. The rate of sweat production is therefore also closely related to the absolute workload. In many sports, including most ball games, short bursts of high intensity activity are separated by variable periods of rest or low intensity exercise.

The time for which high intensity exercise can be sustained is necessarily rather short: the factors limiting exercise performance where the duration is in the range of about 10 to 60 minutes are not clear, but it does seem that substrate availability is not normally a limiting factor and that performance will not be improved by the ingestion of carbohydrate-containing beverages during exercise. Also, even though the sweat rate may be high, the total amount of water lost by sweating is likely to be rather small. Accordingly there is generally no need for fluid replacement during very high intensity exercise, although it is difficult to define a precise cut-off point. In a recent study, however, the effects of an intravenous infusion of saline during cycle ergometer exercise to exhaustion at an exercise intensity equivalent to 84% of VO_2 max were investigated (Deschamps et al., 1989). In the control trial a negligible amount of saline was infused, whereas an infusion rate of about 70 ml/min was used in the other trial. The saline infusion was effective in reducing the decrease in plasma volume which occurred in the initial stages of exercise, although it did not completely abolish this response, and the core temperature and heart rate at the point of exhaustion were both lower in the infusion trial. There was no effect on endurance time which was the same in both trials. The endurance times were, however, short (20.8 and 22.0 minutes for the infusion and control trials, respectively), although the range was large (from about 9 to 43 minutes), and these results support the idea that fluid provision will not benefit exercise performance when the exercise duration is short.

There are also likely to be real problems associated with any attempt to replace fluids orally during very intense exercise. The rate of gastric emptying, which is probably the most important factor in determining the fate of ingested fluid, is impaired when the exercise intensity is high, as described above. Even at rest, the maximum rates of gastric emptying which have been reported are only about half the saline infusion rate (70 ml/min) used in the study of Deschamps et al., (1989) and are commonly much less than this. To achieve a high rate of fluid delivery from the stomach, it is necessary to ingest large volumes, and any attempt to do so when the exercise intensity exceeds about 80% of VO_2 max would almost certainly result in nausea and vomiting.

At lower intensities of exercise, the duration of exercise is inversely related to the intensity. In an activity such as running, this holds true for populations as much as for individuals. As the distance of a race increases, so the pace that an individual can sustain decreases (Davies & Thompson 1979); equally, in an event such as a marathon race where all runners complete the same distance, the slower runners are generally exercising at a lower relative (as a percentage of VO_2 max) and absolute work intensity (Maughan & Leiper 1983). Because the faster runners are exercising at a higher workload, in absolute as well as in relative terms, their sweat

rate is higher, although this effect is offset to some extent by the fact that they generally have a lower bodyweight: because the faster runners are active for a shorter period of time, however, the total sweat loss during a marathon race is unrelated to finishing time (Maughan 1985). The need for fluid replacement is therefore much the same, irrespective of running speed, in terms of the total volume required but there is a need for a higher rate of replacement in the faster runners. Among the fastest marathon runners, sweat rates of about 30 to 35 ml/min can be sustained for a period of about 2 hours 15 minutes by some runners. The highest sustained rates of gastric emptying reported in the literature are greater than this, at about 40 ml/min (Costill & Saltin 1974; Duchman et al., 1990). These gastric emptying measurements were made on resting subjects, and it is possible that there may be some inhibition of gastric emptying at the exercise intensity (about 75% of VO_2 max) at which these elite athletes are running (Costill & Saltin 1974). In the slower runners, the exercise intensity does not exceed 60% of VO_2 max, and gastrointestinal function is unlikely to be impaired relative to rest (Mitchell et al., 1989; Rehrer et al., 1989b). In these runners, sweat rates will also be relatively low (Maughan 1985).

Although in theory, therefore, it should be possible to meet the fluid loss by oral intake, gastric emptying rates of fluids are commonly much lower than the maximum figures quoted above, and it is inevitable that most individuals exercising hard, particularly in the heat, will incur a fluid deficit. It is surprising, and remains unexplained, that the majority of recreational long distance runners appear to incur a relatively small fluid deficit in spite of their low rates of fluid intake (Maughan 1985; Noakes et al., 1988).

Composition of Drinks

In spite of the definitive statement by the American College of Sports Medicine in their 1984 Position Statement on the prevention of thermal injuries in distance running that cool water is the optimum fluid for ingestion during endurance exercise, some of the evidence presented above indicates that there may be good reasons for taking drinks containing added substrate and electrolytes. In prolonged exercise, performance is improved by the addition of an energy source in the form of carbohydrate; the type of carbohydrate does not appear to be critical, and glucose, sucrose and oligosaccharides have all been shown to be effective in improving endurance capacity. Recent studies have suggested that long chain glucose polymer solutions are more readily used by the muscles during exercise than are glucose or fructose solutions (Noakes 1990), but others have found no difference in the oxidation rates of ingested glucose or glucose polymer (Massicote et al., 1989; Rehrer 1990). Massicote et al., (1989) also found that ingested fructose was less readily oxidised than glucose or glucose polymers. Fructose in high concentrations is best avoided on account of the risk of gastrointestinal upset. The argument advanced in favour of the ingestion of fructose during exercise, namely that it provides a readily available energy source but does not stimulate insulin release and consequent inhibition of fatty acid mobilisation, is in any case not well founded: insulin secretion is suppressed during exercise.

The optimum concentration of sugar to be added to drinks will depend on individual circumstances. High carbohydrate concentrations will delay gastric emptying, thus reducing the amount of fluid that is available for absorption: very high concentrations will result in secretion of water into the intestine and thus actually increase the danger of dehydration. High sugar concentrations (>10%)

may also result in gastrointestinal disturbances. Where there is a need to supply an energy source during exercise, however, increasing the carbohydrate content of drinks will increase the delivery of carbohydrate to the site of absorption in the small intestine: although the volume emptied from the stomach is reduced as the carbohydrate concentration increases, the amount of carbohydrate emptied is increased, and so is the rate of carbohydrate oxidation by the muscles.

There is no good evidence to support the addition of electrolytes other than sodium to drinks to be consumed during exercise. Sodium will stimulate carbohydrate and water uptake in the small intestine and will help to maintain extracellular fluid volume. Most soft drinks of the cola or lemonade variety contain virtually no sodium (1 to 2 mmol/L; sports drinks commonly contain 10 to 25 mmol/L; oral rehydration solutions intended for use in the treatment of potentially fatal diarrhoea-induced dehydration have higher sodium concentrations, in the range 30 to 90 mmol/L). A high sodium content tends to make drinks unpalatable, and it is important that drinks intended for ingestion during or after exercise should have a pleasant taste in order to stimulate consumption. Specialist sports drinks are generally formulated to strike a balance between the twin aims of efficacy and palatability, although it must be admitted that not all achieve either of these aims.

When the exercise duration is likely to exceed 3 to 4 hours, there may be advantages in adding sodium to drinks to avoid the danger of hyponatraemia, which has been reported to occur when excessively large volumes of low sodium drinks are taken (Noakes et al., 1985). Sodium is also necessary for post event rehydration, which may be particularly important when the exercise has to be repeated within a few hours: if drinks containing little or no sodium are taken, urine production will be stimulated and most of the ingested fluid will not be retained. When a longer time interval between exercise sessions is possible, replacement of sodium and other electrolytes will normally be achieved from the diet.

It is often stated that there is an advantage to taking chilled (4°C) drinks as this accelerates gastric emptying and thus improves the availability of ingested fluids. The most recent evidence, however, suggests that the gastric emptying rate of hot and cold beverages is not different. In spite of this, there may be advantages in taking cold drinks, as the palatability of most carbohydrate-electrolyte drinks is improved at low temperatures.

Environmental Conditions

The ambient temperature and wind speed will have a major influence on the physical exchange of heat between the body and the environment. When ambient temperature exceeds skin temperature, heat is gained from the environment by physical transfer, leaving evaporative loss as the only mechanism available to prevent or limit a rise in body temperature. The increased sweating rate in the heat will result in an increased requirement for fluid replacement. Other precautions such as limiting the extent of the warm-up prior to competition and reducing the amount of clothing worn will help to reduce the sweat loss and hence reduce the need for replacement. For endurance events at high ambient temperatures, there may also be a need to reduce the exercise intensity if the event is to be successfully completed.

When the humidity is high, and especially in the absence of wind, evaporative heat loss will also be severely limited. In this situation, exercise tolerance is likely to be limited by dehydration and hyperthermia rather than by the limited availability of metabolic fuel. Suzuki (1980) reported that exercise time at a workload of 66% VO_2 max was reduced from 91 minutes when the ambient temperature was 0°C to 19 minutes when the same exercise was performed in the heat (40°C). In an unpublished study in which 6 subjects exercised to exhaustion at 70% VO_2 max on a cycle ergometer, we found that exercise time was reduced from 73 minutes at an ambient temperature of 2°C to 35 minutes at a temperature of 33°C: exercise time in the cold was increased by ingestion of a dilute glucose-electrolyte solution, but in the heat, the exercise duration was too short for fluid intake to have any effect on performance. Although fatigue at these work intensities is generally considered to result from depletion of the muscle glycogen stores, this is clearly not the case when the ambient temperature is high, as this would require the rate of muscle glycogen utilisation to be increased two-fold in the heat and this did not occur.

Supply of water should take precedence over the provision of substrate during exercise in the heat. There may therefore be some advantage in reducing the sugar content of drinks, to perhaps 2 to 5%, and in increasing the sodium content, to something in the range 30 to 50 mmol/L. Conversely, when exercise is undertaken in the cold, fluid loss is less of a problem, and the energy content of drinks might usefully be increased. Carbohydrate concentrations of up to about 15% are generally well tolerated if given as glucose polymers and some individuals can tolerate concentrations in excess of 20%. If given as free glucose, such solutions usually result in diarrhoea.

State of Training and Acclimation

It is well recognised that both training and acclimation will confer some protection against the development of heat illness during exercise in the heat. Although this adaptation is most marked in response to training carried out in the heat (Senay 1979), endurance training at moderate environmental conditions will also confer some benefit. Among the benefits of training is an expansion of the plasma volume (Hallberg & Magnusson 1984). Although this condition is recognised as a chronic state in the endurance-trained individual, an acute expansion of plasma volume occurs in response to a single bout of strenuous exercise: this effect is apparent within a few hours of completion of exercise and may persist for several days (Davidson et al., 1987; Robertson et al., 1988). Circulating electrolyte and total protein concentrations are normal in the endurance-trained individual in spite of the enlarged vascular and extracellular spaces, indicating an increased total circulating content (Convertino et al., 1980).

The increased resting plasma volume in the trained state allows the endurance trained individual to maintain a higher total blood volume during exercise (Convertino et al., 1983), allowing for better maintenance of cardiac output. In addition, the increased total extracellular water provides for an increased sweating rate which limits the rise in body temperature (Mitchell et al., 1976). These adaptive responses appear to occur within a few days of exposure to exercise in the heat. In a series of papers reporting the same study, Mitchell et al., (1976), Wyndham et al., (1976) and Senay et al., (1976) followed the time course of changes in men exposed to exercise (40 to 50% VO_2 max for 4 hours) in the heat (45°C) for 10 days. Although there were marked differences between individuals in their responses, resting plasma volume increased progressively over the first 6

days, reaching a value about 23% greater than the control, with little change thereafter. The main adaptation in terms of an increased sweating rate and an improved thermoregulatory response occurred slightly later than the cardiovascular adaptations, with little change in the first 4 days.

Although there is clear evidence that acclimation by exercise in the heat over a period of several days will improve the thermoregulatory response during exercise, this does not affect the need to replace fluids during the exercise period. Better maintenance of body temperature is achieved at the expense of an increased water (sweat) loss. Although this allows for a greater evaporative heat loss, the proportion of the sweat which is unevaporated and which therefore drips wastefully from the skin is also increased (Mitchell et al., 1976). The athlete who trains in a moderate climate for a competition to be held in the heat will, however, be at a disadvantage on account of his inability to sustain a high sweat rate.