The basics of thermoregulation

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Most endurance athletes have had experiences with stressful environmental conditions while training or competing. Elevated ambient temperature and humidity are the typical culprits; they require enhanced cardiovascular and thermoregulatory responses by the body in order to maintain a core body temperature that doesn’t exceed tolerable levels.

These responses take place on a body-wide level, employing numerous physiological systems working in conjunction to obtain the desired effect: an inner environment that is effective for exercise. The brain initially senses increases in body temperature at the hypothalamus, a central-brain region that controls many autonomic (or automatic) functions of the body. Upon sensing this increase, it sends the messages to different regions:

- To the skin: activation of sweat glands to wet the skin;
- To the cardiovascular system: dilation of cutaneous blood vessels, so that heat can be more easily dissipated;

- To the endocrine system: release of hormones such as anti-diuretic hormone (ADH) to retain water and sodium (Na+) in the kidneys to offset fluid loss from sweat;
- To the urinary system: also to retain water and Na+ to offset fluid loss.

In comfortable environments, non-sweat-related heat loss mechanisms form the bulk of heat exchange from your body. Radiative heat transfer occurs through the transfer of energy in waves to another medium, like air. Conductive and convective heat transfer occurs through the shunting of blood to the skin surface. However, the amount of heat transfer possible is dependent on the difference in temperature between your skin and the environment. Therefore, as the ambient temperature increases, these pathways become less effective. Worse yet, once air temperature reaches or exceeds the skin temperature (usually around 93 to 98 degrees F.) the skin can actually gain heat through convection and radiation, making these methods of heat loss entirely ineffective.

With increases in the heat load, evaporative heat loss (sweating) through the production and evaporation of sweat from the skin surface becomes predominant in thermoregulation. This is a very effective pathway for heat transfer in hot environments, as it is minimally affected by the temperature gradient between your body and the environment. However, evaporative heat loss is greatly impaired in conditions of high humidity, as it reduces the moisture gradient between your skin and the environment. In dry environments, evaporation occurs quickly and efficiently, but as the relative humidity in the air climbs to 50-70%, evaporative rates slow and the skin must retain more heat, becoming red and hot.

The increased exercise and thermal stress on the body manifests itself on the physiological systems of the body in a variety of ways. Many athletes have noticed that they have higher heart rates when working in the heat. The cardiovascular system naturally increases heart rate (HR) and blood ejection per beat (stroke volume, or SV) during exercise, and diverts blood away from "non-essential" organ systems such as the digestive system–– not typically in use during exercise. While muscles get more blood this way, so does the skin, leading to a more efficient heat loss strategy. That being said, exercise also increases blood pressure, which can cause up to a 5-10% fluid loss from the blood (plasma) during the initial minutes of exercise. This loss of plasma water occurs because of changes in "Starling forces" which accompany increased perfusion pressure and capillary area. Add to this the increased sweat response, and blood volume decreases as exercise continues. Now, due to the decreased volume of blood, the heart must deal with a smaller stroke volume per beat and therefore increases heart rate to compensate. This phenomenon is known as "cardiovascular drift", and is the major contributing factor for elevated heart rates in hot and humid conditions. The thermoregulatory system becomes less efficient as fluid losses increase, and cardiovascular strain becomes more prevalent along these timelines.

Your ability to utilize energy and energy stores in your body is also affected by heat load and the ongoing cardiovascular changes that you're experiencing. Pooling of blood in the limbs and the skin can reduce blood flow further, resulting in decreased oxygen delivery to working muscles (Sawka 1988). This can obviously adversely affect the ability to exercise at previous levels, and begins a shift from aerobic work to anaerobic work−−as well as an increased O2 usage, increased O2 debt, and increased blood lactate levels (Dimri, Malhotra et al. 1980). This shift results in a higher level of glycogen usage, since anaerobic exercise uses stored carbohydrates at a faster rate than aerobic exercise, which typically uses a higher percentage of fat as an energy source (Sawka and Wenger 1988).

So, in summary, the body has several effective mechanisms to deal with increases in body temperature, but extreme environmental conditions can quickly render these mechanisms insufficient to maintain a reasonable core body temperature. Over longer periods of exercise in these conditions, cardiovascular performance, muscular endurance, and stored energy reserves all suffer, largely because of reduced blood volume resulting from fluid loss.

For those that have been following their training schedules religiously, here's some good news: research has shown that improved cardiovascular fitness (as indicated by VO2 max) will have a positive influence upon the thermoregulatory responses of the body during exercise (Greenhaff 1989). This includes an elevated sweating rate (assuming "co-operative" environmental conditions), decreased sodium concentration in sweat, a lower resting core temperature, a higher core temperature at fatigue, and a faster rate of acclimation to heat (Cheung, McLellan et al. 2000). If nothing else, being fit is the best way to ensure you survive in the heat. Fluid intake is still essential, though, as an elevated sweating rate can increase your rate of dehydration.

In the next section, we'll address fluid loss and the mechanisms of rehydration that have been proven to be most effective.

PART 2: FLUID LOSS.

So you're in the middle of a lava field and you're lucky enough to be sweating like mad. You should be thankful that, as a trained athlete, you are somewhere between 50-60% water. Even your bone, the densest material in your body, is as much as 50% water. This water is used to cool you, to remove the metabolic wastes you are producing while running, and to provide structure and support to your cells, muscles, bone and organs.

And now you're getting low in water. As little as a 2 percent decrease in body water content can impair performance somewhat, and after 5 percent you're experiencing significant losses in muscle strength, simply because your muscle blood flow is decreased, metabolic wastes are not removed efficiently, and heat is no longer dissipating as effectively. Typically, an athlete will lose sweat in the amount of 0.8-1.4 liters an hour, although rates have been shown to occur in excess of 3.7 L/h (!) in very hot and humid conditions (Armstrong, Hubbard et al. 1986). A major reduction in body weight (2-8%) is not uncommon in athletes even if they rehydrate, because of a delay in thirst response and a maximal stomach fluid emptying rates in the range of 0.8-1.2 L/h (Coyle and Montain 1992). And the precious VO2 max that you've been relying so heavily upon? The effects of dehydration on your cardiovascular output through decreased plasma volume significantly affect your endurance capability (see Table 1).

Table 1: The impact of dehydration on exercise

(Adapted from Armstrong, 2000)			
Weight loss	Exercise environment	Vo2max change	Endurance change
-2%	Hot	-10%	-22%
-4%	Hot	-27%	-48%
-5%	Mild	-7%	-12%

Fluid Replacement Strategy

The basis of all fluid replacement is simple: your body has to fight between central (i.e. organs, muscles, etc.) and peripheral (i.e. skin, thermoregulation) needs for fluid. By replacing the fluid you have lost, this battle for fluid is lessened. Without replacement, the central fluid needs almost always win out, reducing your rate of heat dissipation, and core temperature increases until you collapse. Keep in mind that there is a lag time between drinking a fluid and it actually getting into your body, as the fluid first has to empty from your stomach and then be absorbed from the intestine into the bloodstream. Coupled with a delayed thirst response that often does not activate until you are already 2-3% dehydrated, it is essential that you drink early on in exercise. A series of studies by the Canadian military (Cheung, McLellan et al. 2000) demonstrated that maintaining hydration prior to and during exercise was the biggest determinant of exercise performance, dominating over any benefits accrued from improved fitness or acclimatization.

The American College of Sports Medicine (Convertino, Armstrong et al. 1996) suggests that 400-600ml of fluid be ingested 2 hours before exercise to ensure euhydration (or normal hydration levels). The 2 hours allows for sufficient time to ensure that excess body water is excreted in the form of urine prior to exercise. In hot conditions, an increase in this volume would be judicious. For those that take things to the extreme, the practice of pre-race hyperhydration has had relatively little scientific support, including studies in excess water ingestion (Greenleaf and Castle 1971), saline ingestion (Barr, Costill et al. 1991), and saline infusion (Castellani, Maresh et al. 1997).

Only has the combination of glycerol and water ingestion been shown to have moderately positive effects. One of the more recent studies using glycerol showed that increased water retention and decreased urine output occurred after glycerol and water ingestion (Freund, Montain et al. 1995), and another earlier study showed that lower rectal temperatures resulted from glycerol hyperhydration during 1.5 hours of moderate exercise in the heat (Lyons, Riedesel et al. 1990). Other studies have shown no effect on thermoregulation, but almost all have shown an increase in total body water, typically through reduction in urine output. For those who want to try their own glycerol supplementation, doses should not exceed 1.2 grams of glycerol per kilogram of body mass. Be warned that weight increases and feelings of bloatedness may occur due to the increased water retention. (*Editor's note: for more on this subject––and with conclusions not necessarily parallel to those in the present article, see Slowtwitch article on Euhydration*).

During the event, it has been shown that fluid replacement should occur at least 30 minutes before it’s needed––that means early and often. Following the conventional advice that recommends smaller amounts of fluid intake more frequently is a good idea, but if this isn’t possible, don’t worry. A study (Montain and Coyle 1993) investigating fluid ingestion in differing amounts and at different times during exercise has demonstrated that thermal and cardiovascular responses are similar, regardless of whether the fluid was ingested entirely at the beginning or evenly spaced throughout exercise. It might be difficult to consume fluids during certain parts of a race or training effort, so if you anticipate a difficult stretch, get more fluid in earlier. For appropriate guidelines, see the end of this section for more information on drink composition.

After the event, fluid intake is regulated by both the osmolarity of the plasma (i.e. a dehydrated person will be more hyperosmotic and thus take up fluid faster), and also by gastric and oropharyngeal factors (Rolls and Rolls, 1982). There is a period of delayed rehydration after thermal dehydration, which is involuntary and due largely to losses of Na^+ in sweat and due to postural orientation (Greenleaf 1992). This means that your state of dehydration is going to exist for an amount of time after you complete exercise, no matter what you drink during that period. It has been shown that a glucose-electrolyte solution can decrease the period somewhat, and plasma volume increases are more rapid with these solutions.

Many post-exercise drinks lately such as Endurox R4 and Boost have been touting the benefits of protein replacement after exercise, and there are certainly benefits to doing so. However, considering the hydration state and the period of involuntary dehydration, these types of drinks will actually slow fluid absorption and provide improper hydration. Save these for the extended rehydration period, starting approximately 4-5 hours after the completion of exercise. Fluid, electrolytes, and simple fluid-based glucose concentrations should be your major intake for the 2 hours following exercise. The same applies for eating: If you are eating right after the event, you're slowing fluid absorption, and also prolonging rehydration, since ingestion of food often diminishes the thirst drive. Try to restrict your post-race eating for at least 2 hours, opting for liquid forms instead. If you must, stick to easily digested fruits such as bananas and oranges. Those that state that your carbohydrate uptake is at its peak in the first hour after racing are only partially right––eating carbohydrates in solid form won't help your situation much. The digestive system is not ready to absorb large amounts of carbohydrates in your dehydrated state, and considering the possible diminishing effects on your thirst drive, it would be better to delay eating significant amounts of solid food until you've adequately hydrated. Or, try light concentrations of carbohydrates in the fluids you're replacing.

One of the most effective methods of dehydration quantification is simple, nude body weight. You're going to lose water during exercise, and that water weighs about one kilogram per liter. It's somewhat impractical to get naked and find a scale in the middle of a race, so you're basically running on guesswork until after the race. But, there's no stopping you getting weighed at home after the race and quantifying your water loss that way. Note there has been research that shows you may have to consume 150% to 200% of the fluid you may have lost to return to your original body weight (Maughan and Shirreffs 1997). If you replace the weight you have lost with fluids, you are at the very least meeting your optimal rehydration strategy, and likely exceeding it.

And, if you're into urine color as a good monitor of hydration status, you're not far off: Pale yellow urine has been shown to be an excellent indicator of proper hydration (Armstrong, 2000). Keep in mind that ingestion of B and C vitamins can color your urine orange, possibly giving an improper indication of hydration. If your urine is totally clear or looks like water, you're overdoing it. And for the athlete that has it all, pick up a refractometer (around $200) that monitors specific gravity of urine for a really accurate sampling.

Sodium (Na+) Intake

According to previous study during running races, sodium chloride (NaCl) losses on hot days over 10km will range between 0.5-6 grams, anywhere from 2-29 grams for a marathon distance, and 54-93 grams for a 100 mile race––see (Armstrong, Costill et al. 1985) for more information). These Na+ losses can clearly exceed regular Na+ intake from a normal diet.

Keep this in mind: Racing in hot climates over prolonged distances is likely the only time you would ever need to take in extra Na+. Regular training and racing in temperate climates over shorter distances likely won't tax your Na+ levels enough to justify taking in extra Na+. However, it's important not to go the other way either, and start overloading on electrolytically imbalanced fluid (i.e. straight water) only. This can create an osmotic imbalance in the body, thus making your relative Na+ level too low. Recall from your long-past biology classes that the osmolarity of most blood and body fluids is in the neighborhood of 280-300mOsm, which means there is a great deal of solutes and sodium dissolved in it (comparison: tap water is about 5mOsm, Gatorade is about 340mOsm). By taking in lots of water without any electrolytes, you are adding large amounts of osmotically imbalanced fluid and therefore diluting your body fluid excessively. Overdosing on water alone may result in a condition called hyponatremia, with symptoms of fatigue and collapse. Note that the symptoms are very similar to those due to heat exhaustion and dehydration, and may be tricky for many race doctors to correctly diagnose.

How do you avoid this? Eat normal meals and don't restrict or increase Na+ intake before or during competition. The key is to match your electrolyte intake with your water intake. During regular exercise, expect to lose 0.5-1.5 kg of body weight from fluid loss, which means you'll have to consume a similar amount of fluid (0.5-1.5L per hour of exercise) during or after you're done. Any more than this, and you might just be overdoing it.

Still, an Ironman race in Hawaii doesn't qualify as 'regular' exercise in a 'temperate' environment. Salt supplementation for races of this extremity is therefore sometimes a good idea to prepare for racing in hot climates, although the supplementation is recommended to begin during the initial 3-5 days of heat exposure before competition, simply because the kidneys require 3-5 days of heat exposure to maximally conserve Na+ (Hubbard et al, 1986). (*Editor's note: for more on this subject see Slowtwitch series on Race fueling*)

What!? I need 3-5 days of pre-exposure to heat? Won't I get tired standing around in the heat all that time? Absolutely not––if you hydrate and replace electrolyte properly. In fact, heat acclimatization is the best thing you can do to prepare to race in hot climates. Those who think that "jumping in" to the climactic conditions just before the race to save themselves the suffering are only setting themselves up for disaster. In the next section, we'll discuss the physiology and techniques behind acclimatizing yourself to the heat.

Carbohydrate (CHO) intake

During prolonged exercise, it has been shown that the maximum rate of substrate oxidation appears to be around 1gram per minute near the end phases of the exercise period (Rehrer et al, 1992); typically it is slightly less. It's no secret that taking in forms of CHO while exercising produces a glycogen-sparing effect, but in liquid form, how much do you really need? It makes sense that you wouldn't need to take in much more than you're burning, and considering that high CHO solutions limit fluid delivery to the intestine, too much of the energy drink powder might not be the best idea.

If you're determined to follow the hydration guidelines established above, and you're replacing the amount of fluid that you're losing in terms of overall quantity, then a 2-3% carbohydrate (CHO) solution should result in adequate substrate replacement (Convertino, Armstrong et al. 1996). Considering that a 6-8% CHO beverage can replace up to 120g of CHO per hour (assuming proper rehydration rates), then you could be almost doubling your maximal rate of substrate oxidation, and possibly slowing fluid absorption rates. Keep that in mind when mixing your bottles ahead of time.

In the meantime, a committee on military nutrition (you think what you guys do is hard? Try doing it with a 32kg backpack and in full military gear in the same heat!) came up with the following tentative recommendations for fluid concentrations during exercise in the heat:

1. Include sodium in the amount of 20-30meq/liter, and potassium in the amount of 5-10meq per liter to offset potential electrolyte losses. Any more than this and your fluid absorption rates will drop. For comparison's sake, your regular Gatorade mix will have two to three times this much sodium, so some dilution may be necessary.
2. Glucose actually aids in sodium absorption, as well as maintaining blood carbohydrate levels. Include glucose in the amount of at least 0.9%, and up to 2.5% total concentration. Any higher amounts than this significantly slow gastric emptying rates and water absorption. Again, for comparison's sake, most carbohydrate drinks have somewhere between 5-10% carbohydrate in solution and may be preventing adequate fluid absorption.
3. A small amount of fructose should be present, as this aids in potassium absorption in the jejunum (part of your small intestine). Glucose alone can cause K+ secretion (leading to loss).

PART 3: CLOTHING FOR EXERCISE IN THE HEAT

Normally, we feel comfortable wearing around our race T-shirts, cotton though they may be. Under normal conditions, the human body produces little sweat and cotton seems comfortable enough. In the heat or while exercising however, the human body requires evaporation of sweat from the skin's surface, and this is when clothing becomes more essential to our comfort and thermoregulatory ability. The layer of fabric immediately next to the skin determines the partial pressure of water vapor in the space between the skin and the fabric, and it has been shown that the lower this partial pressure is, the more comfortable the wearer is (Wang and Yasuda, 1991). Cotton and wool are hygroscopic (or water-absorbing) materials and absorb a great amount of moisture from the skin, but this wet material then provides a barrier against effective moisture evaporation from the skin. Polyester and other synthetic materials are non-hygroscopic, absorbing little moisture, and coupled with the fact that they have hydrophilic (water-loving) fiber surfaces, they can transfer moisture quite readily.

Triathletes today wear clothing that is a compromise between different functions––aero/hydrodynamic efficiency, and thermal protection/dissipation. Add to this the obligation to be comfortable, and also to be "noticed"––possibly due to sponsor requirements––and you'll see any number of black, white, neon and colored racing outfits on any given day. A unique study (Nielsen 1990) examined the efficacy of different types of clothing colors and materials on thermal strain in exercising subjects. Their backs were exposed to an artificial 'sun' wearing either white or black polyester or cotton. It was found that differences in short-wave radiation gains between white and black clothes were small, simply because the transparency of the white materials allowed a larger percentage of the radiation to penetrate the clothing. Also, the sun-exposed areas had much higher surface temperatures, which promoted dry heat loss, but there was little difference between black and white clothes in this regard as well. It was found, however, that overall heart rates and sweat losses were significantly lower for white polyester materials than black cotton-based materials, showing that thermal strain is clearly reduced by wearing light colors in a synthetic material. So, black or dark blue synthetic materials are not likely to pose any more of a thermal risk, but avoid cotton.

Speaking of black and blue synthetic materials, everybody by now has heard or seen about the new speed suits for the Olympic swimmers produced by several companies, most notably the Aquablade technology by Speedo. Now in triathlon form as well, these materials clearly conform to the aero/hydrodynamic school of function, but what about the thermal side? The hydrophobic beading/flow activity of the new skin suits is great for shedding water and promoting laminar water flow, but it also provides a barrier to evaporation from the skin. Essentially, a microclimate is created within the suit, right next to the skin, that doesn't allow water vapor to permeate as effectively from the body, retaining heat next to the skin and creating a greater thermal strain. Research has shown that hydrophilic properties of fabrics are of physiological significance for reducing heat strain during exercise (especially when influenced by wind) (Kwon, Kato et al. 1998), and a material that makes it difficult for moisture to travel readily through it can adversely affect body temperature regulation. Maybe these suits are best left in the water; more research is definitely warranted in this regard.

Other research in local ventilation and cooling has shown that torso skin temperatures can decrease if leg ventilation is increased, and that trunk ventilation on its own can decrease internal temperature strain (Desruelle, Bothorel et al. 1996). Remember when Simon Whitfield ran across the finish line at Sydney to claim the gold medal? The entire front of his torso was exposed as the zipper to his suit was undone, so it was an effective thermoregulatory adaptation. Racing outfits with front zippers are definitely a good idea if you're going to be in hot and humid conditions. Racing in full leg tights, on the other hand, may not be––ventilation to the legs should be as optimal as possible to ensure that their vasodilation and sweating responses are maximized. This means that half-tights or running shorts are most effective in providing a positive thermoregulatory adaptation while exercising in the heat. Avoid full-length tights.

Let's assume that we all have an optimal clothing configuration. We are now left to cool parts of the body somehow, and during a race, we've got little choice aside from fluid replacement––pouring water or ice over different parts of the body. Another study (Young, Sawka et al. 1987) may prove enlightening on this point: Cooling arms during upper body exercise provides no thermoregulatory advantage, although cooling the thigh surfaces during lower body exercise does provide an advantage. The theoretical basis for the above finding may lie in the differences in the primary avenues of heat exchange between upper and lower body exercise. In hot environments, dry heat exchange (that is, radiation and convection) of the torso is greater with upper body exercise than with lower body exercise; lower body exercise elicits greater radiative, convective or evaporative cooling at the legs, depending on which of these avenues is favored by the ambient environmental conditions (Young, Sawka et al. 1987). Legs also have better sweating and vasomotor responses. You could apply this practically by targeting your water at the lower body during a race, rather than pouring it on the torso or arms, which aren't the primary active muscles, anyway.

That being said, cooling of the skin by dousing or wetting with cold water seems to have little effect on decreasing thermal strain or core temperature in the heat. Aside from the brief psychological value of doing so, the little amount of water that remains on the skin for evaporation doesn't really do much. For those that are of the mindset that they should wear as little clothing as possible and will simply run through a lot of hoses, change it. Proper clothing strategy is certainly the more effective strategy for thermoregulation than local skin cooling.

Of all the external cooling strategies though, one more recent study (Desruelle and Candas 2000) may actually have something to offer; it showed that local cooling of the head may represent a thermoregulatory advantage. In exercise trials conducted in the heat breathing cold air, cooling the skin of the face, or combining the two, it was shown that head skin cooling caused a reduction in heat strain. On a more practical level, it could be suggested that if you're going to do something to cool your body off, ice in the cap is the most effective strategy.

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HEAT ACCLIMATIZATION CONSIDERATIONS FOR ENDURANCE ATHLETES

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Introduction

Acclimatization to the competition environment is essential if the environmental characteristics in which you are conventionally training in differ significantly. The aim of heat acclimatization is to build up a degree of heat tolerance and allow physiological adaptations to occur that improve exercise performance. These adaptations allow your body to more effectively deal with a rise in body temperature. In this case a hot and humid or hot and dry environment will be addressed.

First some definition of terms; acclimation refers to the process of becoming adapted by so-called artificial means such as an environmental chamber or sweat clothing, more of which will be discussed later; acclimatization refers to the process of becoming adapted to the environment by means of actually being in that environment; a temperate environment refers to conditions around 15-20 degrees C, an environment that does not prove to be a great challenge to heat loss. Having said that, Galloway and Maughan (1997) have shown that exercising even in a temperate environment at 21 degrees C heat related fatigue is still a problem and the ideal ambient temperature for endurance performance is around 11 degrees C.

At a critically high core temperature the drive for exercise may be diminished due to negative effects on the motor centers of the brain. An increase in muscle temperature can disrupt the electrolyte balance, calcium release and re-uptake and mitochondrial function and possibly compromise the ability to maintain power output. Building a degree of tolerance to a hot and sometimes humid environment is the aim of acclimation and acclimatization, limiting the detriment to performance and avoiding heat related illness or injury. The acclimatization that can occur will be both physiological and psychological although this article is predominantly concerned with the physiological adaptation the psychological ones cannot be dismissed as the ability to tolerate a challenging environment involves a good degree of motivation. Added to which there is evidence to indicate that the physiological adaptations that occur such as an increase in plasma volume have both physiological and psychological benefits (Armstrong 1998)

Acclimatization to heat is a key element in avoiding heat related disorders. The adaptations that occur throughout your body will take several days, so if you are planning to compete in a hot and/or humid environment an appropriate acclimatization strategy is a must and requires some planning. A common sense philosophy that you will already be familiar with still applies. That philosophy is one of specificity: generally speaking, acclimatization will be specific to the environmental conditions and exercise intensity used in your strategy. This means if your strategy involves simply sitting in a hot environment you will become acclimatized to doing just that and the adaptations that occur will be of little use when you start to exercise in that environment. Essentially you should use the intended environmental conditions and exercise intensity you will be experiencing in competition in your acclimatization strategy. It is worthy to note that the adaptations that can be brought about by acclimating to differing conditions (e.g. hot/dry vs. hot/wet) will be similar and transferable as long as the environments represent the same degree of overall heat stress (equivalent WBGT) (Griefahn, 1997).

The following information is provided based on research predominantly involving young fit and healthy individuals. It is also worthy to note that some individuals respond to a lesser degree than others; that is to say the magnitude of the heat acclimatization that occurs will be greater in some than others.

Why do you need to consider acclimatization to a hot environment?

It is recognized by the American College of Sports Medicine that acclimatization is highly recommended in order to avoid heat related injury while competing in distance events in the heat. It is a widely accepted fact that athletes from temperate climates are disadvantaged when competing in high temperatures and humidities, the negative factors of which can be greatly reduced by a period of acclimatization. If the acclimatization strategy will not allow time spent at the competition venue prior to the event then acclimation to the conditions can be achieved in an environmental chamber. An artificially controlled and easily manipulated temperature and humidity chamber can be used to recreate the desired conditions. Although environmental chambers are generally few and far between they represent the next best thing to actually staying and training in the competition environment. They also usually have the benefit of coming with experienced and qualified staff that can monitor the acclimation process.

Acclimatization to heat is produced by repeated exposure to heat sufficient to raise internal temperature (most effectively accomplished with exercise) and provoke a moderate to profuse sweating. Effects of heat acclimatisation are:

General

- Improved thermal comfort, cognitive and physical performance
- Increased heat tolerance
- Reduced heat strain

Specific

- Plasma volume expansion resulting from increased plasma proteins and increased sodium chloride retention, ranges from +3 to +27%, and is accompanied by a 15-25% decrease in heart rate (Armstrong 1998).
- The cardiovascular changes occur to reduce heart rate and cardiovascular strain.
- Heart rate response is lessened in submaximal exercise, resulting from increased blood volume/stroke volume.
- Improving heat tolerance means that body temperatures, both skin and core are lower following the same intensity training session in the heat at the end of the strategy than before acclimatization due to enhanced heat loss capacity.
- As a result of lower body temperatures skin temperature is lower and in turn the temperature gradient from the body core to periphery is larger, as heat loss is facilitated, less blood flow to the skin is needed for heat transfer and more blood becomes available for the working muscles.
- By making the body more efficient at dealing with the heat, more blood is available to the working muscles, increasing the capacity for work.
- Sweat:
  - Sweating starts earlier (at a lower core temperature).
  - Sweat production may increase in exposed areas and in areas most effective at dissipating heat e.g. Chest, back.
  - Sweat produced is more dilute, conserving mineral stores.

Differences in physiological adaptations do occur between hot/dry and hot/humid acclimation, namely an unchanged sweat rate and greater decrease in mean skin temperature with dry heat when compared to humid heat. Heat acclimation to humid environments can help prevent the fatigue of the sweat glands (hidromeiosis) thus allowing greater sweat rates to be maintained and sweating not to be impaired.

An increased capacity for work also reduces the rate of muscle glycogen use by as much as 50 – 60%, reducing risk of chronic fatigue brought on by many days of training in a stressful environment. It is important to note that the increase in sweat rate causes a greater risk of dehydration; this is a commonly forgotten and needs to be considered when developing rehydration strategies. It is known that excess fluid and electrolytes do not speed up the acclimatization process but without adequate hydration the process is severely impaired.

Time course

The adaptations that take place are analogous to altitude training, they have a response time and the effects have a limited lifetime when the body is removed from the environment. Acclimatization is a gradual process that requires good timing, some physiological adaptations will occur relatively quicker than others these include the heart rate decrease and plasma volume expansion after 3-4 days. Later adaptations such as the increases in sweat rate and sweat dilution usually take longer, with the whole process usually requiring 10-14 days (Armstrong 1991). The same adaptations have been shown to occur with exposure every three days as opposed to consecutive daily periods. The intensity of the training sessions should be between 50 and 75% VO2max, Houmard et al (1990) found that moderate intensity (75% VO2max) short duration (30 –35 min per day) exercise produced heat acclimation in trained subjects. Total exercise times exceeding an hour are probably best, but you'll have to build up to this level gradually, accepting that you'll be moving at a slower pace, and you'll need to hydrate more effectively.

It would appear that the most the sessions can be separated by is three days as it has been shown that, when separated by one week, exercise bouts in the heat had no acclimation effect (Barnett and Maughan 1993). The maximum separation of acclimation bouts is unknown at present, but is somewhere between 4 and 7 days. In terms of the loss of the effects of acclimation, it would appear that the adaptations are relatively slower to be lost than gained and can be regained relatively faster once not completely lost (Pandolf 1977).

Interactions between fitness and acclimation

The physiological adaptations that occur during most endurance based training programs in temperate environments are similar to those that occur during acclimatization (e.g. Hypervolemia or an increase in blood volume) in that some degree of aerobic fitness will provide you with some degree of heat acclimatization. The higher an individual's VO2max the sooner his adaptation may take place, as shown by a shorter time being required before core temperature plateaus during acclimatization sessions (Pandolf 1977). The advantage of being more physically fit when starting an acclimatization strategy is that a fit individual will dissipate a given thermal load at a relatively lower thermal drive (level of heat strain) thereby remaining cooler at the same relative heat strain (Pandolf 1977). In more detail it appears that factors associated with being fit and active and not solely having a high VO2max, such as hypervolemia and changes in muscle metabolism, cardiac function and vasoconstriction/dilation capabilities aid substantially in heat dissipation and the acclimatization process (Pandolf, 1988). Other advantages of being physically fitter stated by Pandolf, (1977) include a slower rate of decay of the adaptations and a faster rate of re-acclimatization.

In terms of how things may differ with age, the most recent research shows that when it comes to thermoregulation and acclimatization it is aerobic fitness and variables such as body fat and weight that dictate the adaptations and ability to deal with the heat. Any difference observed with age therefore may not be due specifically to getting older per se but to differing levels of fitness (Pandolf, 1997).

Alternative methods

In a review on heat acclimatization and the use of extra clothing in temperate conditions Dawson, (1994) discussed the merits of using sweat clothing (clothing that allows little evaporation of sweat) to increase heat strain and stimulate heat acclimation. It was concluded from a number of studies that while being the most convenient method of inducing an additional heat stress, there was little heat acclimation above and beyond regular aerobic training alone. The majority of these studies however, as acknowledged by Dawson, (1994) were performed on field sport athletes in regular training session perhaps lacking the necessary prolonged intensity and elevated core temperature to stimulate the desired responses. It should be noted that some benefits have been found, in two follow-up studies Dawson et al, (1988,1989) where a greater sweat rate and sensitivity and a greater heart rate and core temperature response was observed when training was done in sweat clothing. These responses were found when the training stimulus was perhaps more appropriate, 7 consecutive days of 80 min of high intensity interval training (Dawson et al 1989).

Therefore, there may be some advantages to training in sweat clothing if this is indeed your only option. The important things to note would be that the wearing of clothes to create a greater heat stress will also increase the risk of dehydration due to an increase in sweat rate, and that the adaptations that may occur to allow you to become more heat tolerant will not be as extensive as full heat acclimatization. It is widely agreed that the most important stimulus to the physiological adaptations is to maintenance of an elevated core temperature however this alone will not do the trick.

Exercise program adjustments

So you have managed to wrangle an extra week prior to the competition in which you can acclimatize to the surrounding environment you will be competing in. The problem is that you are faced with a decreased exercise capacity the first few days of acclimation. One of the most important factors is hydration, as the body's water balance will change and large amounts of water will be lost through sweating. Remember that all of the benefits from an acclimation program can be wiped out by improper hydration. You will need to start with a relatively easy sessions 30-45 min at 50-60% VO2max and work up to longer periods and higher intensities. Good indications of the acclimatization process are a reduced training heart rate (when compared to the first few sessions of the strategy), increased sweat rate and reduced core (rectal) temperature response.

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