

Module 1. Water in the body

Unit 1.1 Introduction

Subjects who engage in physical activity usually do so in varying environmental conditions (e.g. temperature, humidity, wind, etc.), which are not always replicated. This variability – which is subject to other factors, such as clothing, hydration status or the athlete's metabolic rate – can induce significant increases in body temperature (Sawka, Wenger & Pandolf, 1996). These increases can cause a heat-loss response in the body through increased blood flow as well as perspiration. Since this response can be variable and, at times, very elevated, the amount of replenished water and/or electrolytes must be sufficient in order to minimize the impact to athletic performance and/or prevent clinical damage to the subject's health (Sawka & Young, 2005).

As evidenced by literature, the quality, quantity and consistency of scientific articles related to this theme is determined as one of the important factors to consider (and, therefore, to keep in mind) in order to achieve improvements when practicing sports.

The extensive documentation on this subject obliges us review, in this Module, the different recommendations regarding rehydration strategies (to be taken into account before, during and after exercising) as well as the assessment of subjects' hydration.

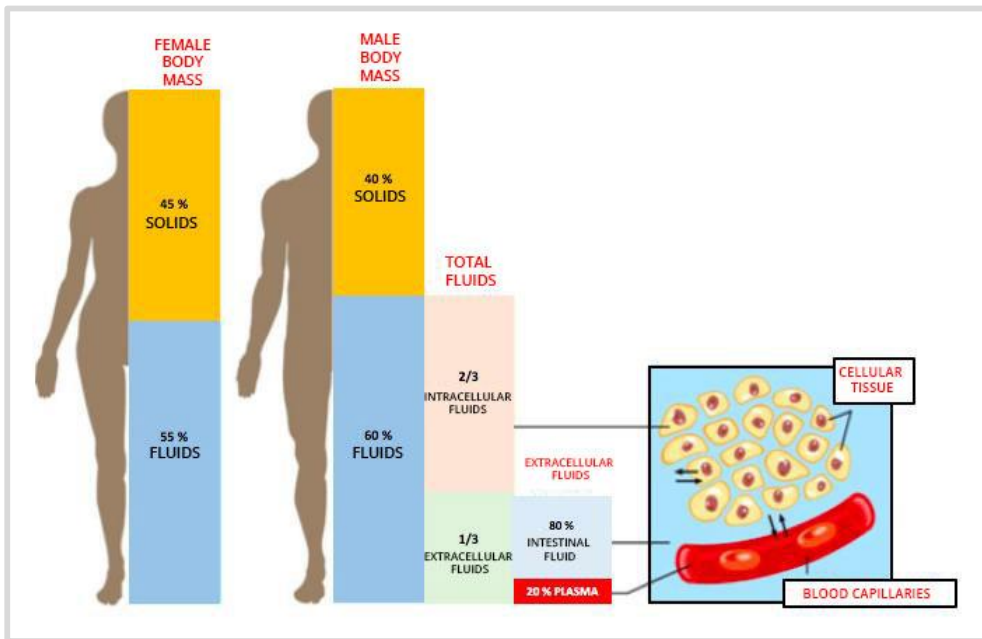
We will also expand on a few basic concepts linked to thermoregulation, as well as a practical approach to how individuals perform in the face of different environmental conditions, energy expenditure, and other factors that must be considered.

1.1.1 The Function of Water

Water is the most abundant component found in the human body, as it constitutes between 40 and 70% of total body mass (variations stem from each subject's gender, age and body composition). While the content between one subject and another is variable, content within the tissue tends to be relatively constant.

The body has two fluid compartments: the first is the intracellular compartment, which refers to the fluid within cells, and it constitutes two-thirds of the total amount of body water; the second is the extracellular compartment, which comprises the interstitial fluid (between cells) and plasma (20% of extracellular liquid). Cerebrospinal, glandular, ear and eye fluids also comprise extracellular fluids.

Figure 1: Distribution by Fluid Compartment



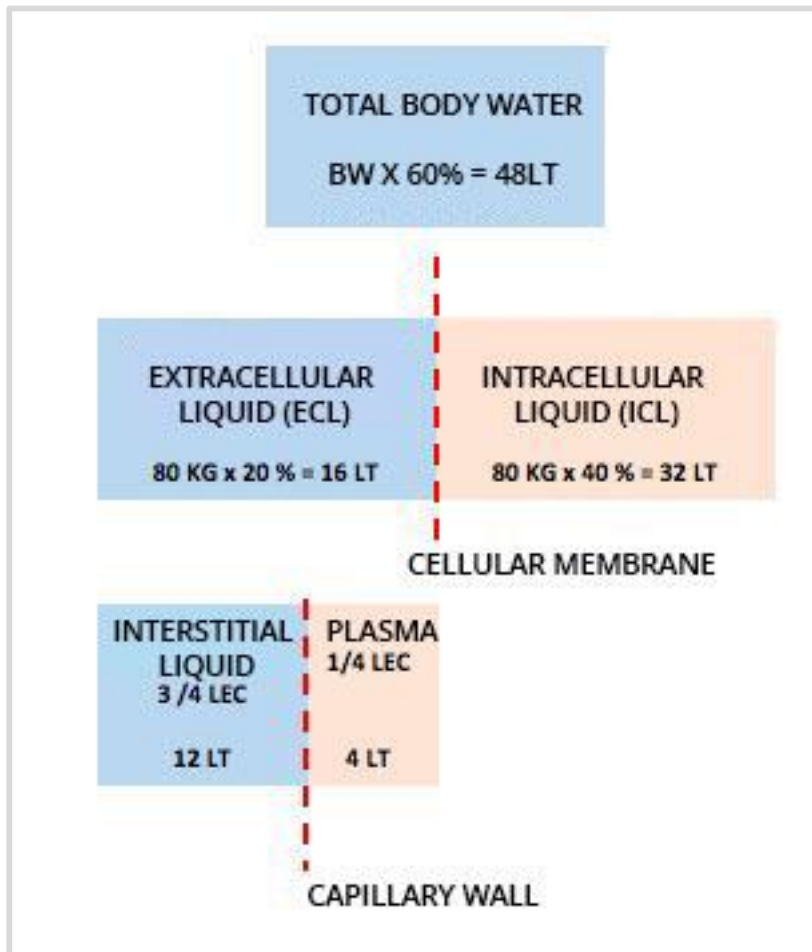
Source: Retrieved from goo.gl/duc7dJ

As we can see in the graph, approximately 60% of total body water is represented in the intracellular compartment, while the remaining 40% corresponds to extracellular sources. Water comprises between 65 and 75% of muscle weight and 10% of fat weight. Taking this into account, people with more fat tend to have a lower percentage of water in their bodies than those who are proportionately leaner.

These volumes reflect averages of a dynamic exchange of liquid between the two different compartments, particularly in physically active men and women. Intense physical training predisposes the body to increase the amount of water distributed within the intracellular compartment, because muscle mass usually increases.

In this game of percentages, we must understand that the largest loss of fluids through sweat comes from the extracellular compartment, through blood plasma.

Figure 2: Distribution of Body Water in a 80 kg Man



Source: Prepared by the author.

1.1.2 Distribution of Body Water and its Composition

Sodium is the principal electrolyte found in extracellular fluid, while potassium is significantly less concentrated. On the other hand, the principal electrolyte found in intracellular fluid is potassium, with small concentrations of sodium. It is essential for the body that this distribution of electrolytes is maintained properly, so that chemical and electrical gradients ensure the integrity of cellular function, allowing electric communication throughout the body.

There's a constant exchange between the two different body water compartments, which depends, to a certain extent, on the osmolality of the bodily fluids. Osmolality refers to the amount of solutes dissolved in 1 kg of solvent. One mole of a non-splittable substance, such as glucose, dissolved in 1 kg of solvent, is equivalent to 1 osmole. One millimole (mmol), on the other hand, is equivalent to one milliosmole (mosm). If the substance is split into two ions, as in the case of sodium chloride, one mole is equivalent to two osmoles. There are many substances in the body that affect osmolality. For example, sodium and its associated anions – chloride and bicarbonate – are the largest source of plasma's osmotically active

components, together with plasma proteins, the latter of which contribute in a small but important way.

Another term related to osmolality is tonicity, which means tension or pressure. When two solutions with different solute concentrations are separated by a permeable membrane, the pressure difference between solutions allows water to move. This pressure is called osmotic pressure. When two solutions have the same osmotic pressure or the same solute content, they are called isotonic.

When we compare two solutions with different solute concentrations, whichever has the highest osmotic pressure is called hypertonic (high solute concentration and low water content) and the other is called hypotonic (low solute concentration and high water content). Water moves between the membrane of a hypotonic solution towards a hypertonic one in order to balance the different concentrations on both sides of the membrane.

This is why the following details are so important, as we will explain the importance of isotonic drinks in rehydration, because, when they have osmolality similar to that of the plasma, it is easier for them to be absorbed by the intestine.

1.1.3 Fluid Balance

Fluid balance is obtained from the net difference between water loss and gain. This balance may vary depending on the factors which impact the relation of the two.

Water intake

In a regular thermal environment (approximately 20°C), a sedentary adult requires nearly 2.5 liters of water per day (beyond the differences we'll review later regarding fluid intake recommendations at the global level).

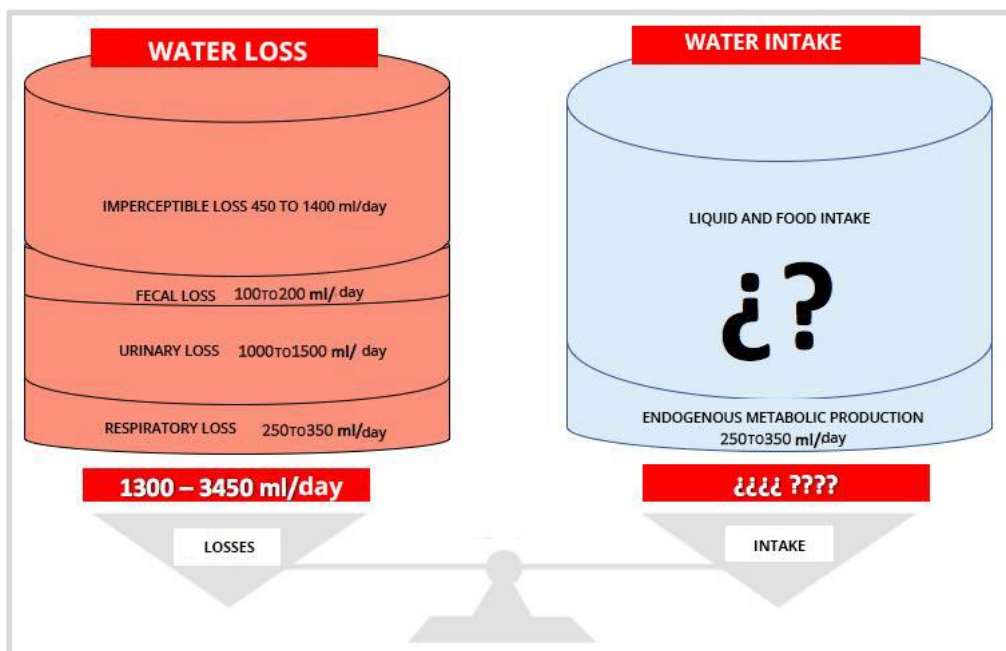
There are three main sources of water intake:

- **Water in food:** generally speaking, water in food constitutes, approximately, around 20 or 30% of the recommended total fluid intake. Fruits and vegetables contain a considerable amount of water, while, on the other hand, baked goods, cereals, chocolates or high-fat foods contain a small amount of water (Food Standard Agency, 2002).
- **Water from fluids:** in normal conditions, the average individual drinks between 1,200 and 1,500 milliliters of water every day, on account of the amount of fluids he or she drinks during the four main meals. Thus, both intense physical activity and thermal

stress increase daily fluid needs by about 4 to 5 times. Food intake is critical in order to ensure complete rehydration on a day-to-day basis. The loss of electrolytes via sweat (e.g., sodium and potassium) must be recovered in order to restore the total body water; this can be achieved mostly through food (ACSM, 2007).

- **Endogenous metabolic production:** the degradation of nutrients' molecules via metabolism forms carbon dioxide and water. This metabolic water provides nearly 14% of the daily water needs of a sedentary person. The metabolism of glucose releases 55 grams of metabolic water. A larger amount of water also stems from protein catabolism (100 grams) and fat (107 grams). Production of metabolic water is usually equivalent to the water lost due to breathing.

Figure 3: Daily Fluid Balance



Source: Prepared by the author.

Water Output

The outflow of water from the body can occur in the following ways:

- **Loss of water through urine:** In normal conditions, the kidneys absorb nearly 99% of the 140 to 160 liters of renal filtration that builds up every day. Because of this, the volume of urine excreted by the kidneys varies between 1,000 and 1,500 milliliters per day.
- **Loss of water through the skin:** each day, nearly 350 milliliters of water are filtered from the deepest tissues through the skin all the way to the body's surface, through imperceptible transpiration. Water loss via the skin also occurs through perspiration produced by sweat glands. Sweat evaporation takes place as a refrigeration mechanism for the body. This produces between 500 and 700 milliliters of sweat

each day, under regular thermal conditions and normal physical activity. Clearly, the amounts lost to this type of fluid loss are completely different depending on the variability of environmental conditions as well as energy expenditure.

- **Loss of water through vapor:** imperceptible water loss through small exhaled drops of water in the air are between 250 and 350 milliliters per day, due to the complete humidification of the inhaled air as it goes through the pulmonary tract. Physical activity affects this source of water loss. In physically active people, the respiratory tract releases between 2 and 5 milliliters of water for each minute of intense training, depending on climatic conditions. Loss of water through the respiratory tract is lesser in warm and humid climate, and greater in cold temperatures (this inhaled air contains less humidity) and high altitudes (because the volumes of inhaled air, requiring humidity, are much greater than at sea level).
- **Loss of water through feces:** intestinal disposal produces between 100 and 200 milliliters of water loss, because fecal matter is nearly 70% water. In the case of diarrhea or vomit, water loss increases to the point that it becomes a dangerous situation, often causing a rupture in the balance of fluids and electrolytes.

1.1.4 Recommendations for Water Intake

The human body has the ability to adapt to the variability between fluid intake and loss due to, on one hand, precise homeostatic regulation, and, on the other, the broad ranges of urine osmolarity that kidneys can achieve.

To this date, and beyond the studies conducted regarding the subject in question, no minimum or maximum values have been precisely identified for informing the general population.

In Table 1, we can see that several world-renowned authorities propose varying reference values regarding total water intake (IOM, 2004).

Table 1: Intake Recommendations, According to World-Renowned Authorities, in Liters per Day

	European Food Safety Authority, 2010	National Health and Medical Research Council, 2006	Institute of Medicine, 2004	World Health Organization, 2003
MALES	2,5	3,4	3,7	Sedentary 2,9
				Active 4,5
FEMALES	2,0	2,8	2,7	Sedentary 2,2
				Active 4,5

Source: Retrieved from www.h4hinitiative.com



Clearly, and in relation to what we have previously seen in this module, we can interpret that, in the face of different environmental conditions as well as the intensity/volume in energy expenditure, recommendations for athletes are completely individual in nature. The American College of Sports Medicine suggests, in its 2007 position, that fluid intake illustrates the need to make recommendations regarding consumption in relation to individual sweat rate (later in the module, we'll see how to obtain it).

Physical activity, ambient temperature and relative humidity are the three factors that determine the broad variability in the amount of water the subject needs to compensate for liquid loss through sweat.

Unit 1.2 Thermoregulation

Temperature can vary between different body parts – sometimes, the skin can be colder than the inside part of the body. Because of this, when we refer to temperature within the body, we must talk about internal temperature, instead of external body temperature.

While it is well-known that normal bodily temperature is around 37°C, during physical training, a variety of factors can affect this number. This is part of what we will develop in this section of the Module, in an attempt to understand how the body typically adjusts in order to maintain its heat balance.

1.2.1 Thermal Balance and Temperature Regulation

As previously stated, thermodynamics tend to vary considerably between resting and exercise. Metabolism's chemical reactions produce caloric gains of considerable levels during muscular activity (Toner, 1996).

Table 2: Thermodynamics during rest and exercise

Condition	Rest	Maximum Exercise
Body heat production (1L of O ₂ Consumption = 4.82 Kcal)	Approximately 0.25 L per min of O ₂ Approx 1.2 Kcal per min	Approx 4 L per min of O ₂ Approx 20 Kcal per min
Capacity of the body to cool down via evaporation	Maximum perspiration Approx. 30 ml per min = 18 Kcal per min	
Increased core body temperature	No increase	Approx. 1°C every 5-7 minutes

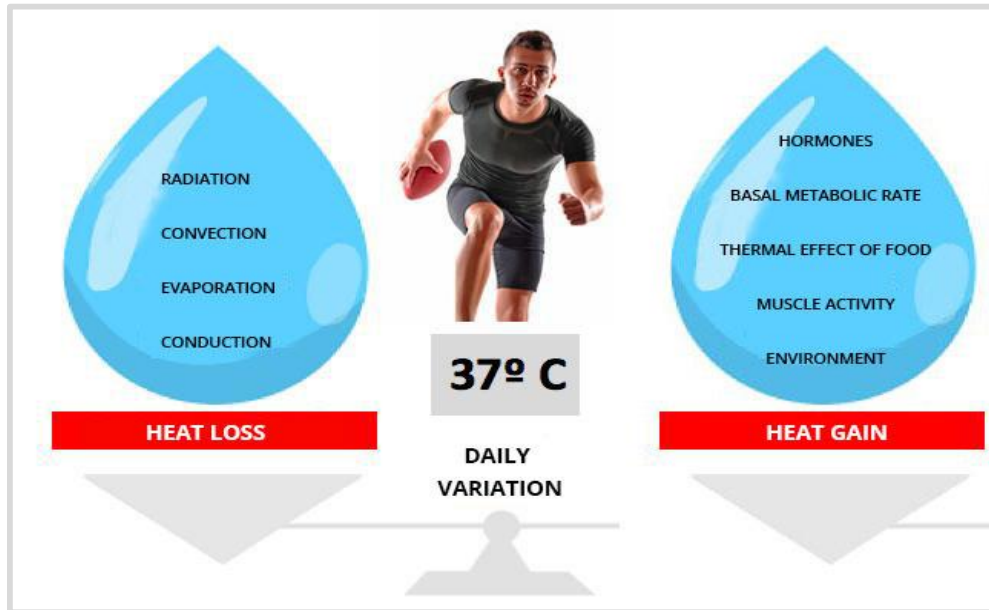
Source: Prepared by the author.

The hypothalamus gives place to the site where temperature regulation is coordinated. To better understand its dynamics, we can draw a comparison with a climate control unit's thermostat, which produces heat in accordance with the information it gathers from the environment.

Generally, if skin receptors detect higher temperatures or if blood temperature rises, the body will make the necessary adjustments in an attempt to lose heat. First, blood may be channeled closer to the skin, so inner heat can come closer to the outside and radiate more easily. At the same time, perspiration and evaporation begins, taking the heat away from the body.

On the contrary, if skin receptors detect lower temperatures or if blood temperature drops, the body reacts in order to conserve heat or increase its production. First, blood will be channeled away from the skin and towards the inner part of the body, which decreases the loss of heat from heat radiation, and keeps vital organs at an adequate temperature. This is where shaking might begin – which is actually muscles contracting – as they produce extra heat by increasing the metabolic rate.

Figure 4: Intervening Factors in Temperature Regulation



Source: Prepared by the author.

1.2.2 Thermoregulation and Cold Temperatures

Generally, regulating central temperature does not require a great physiological effort. When we're exposed to extreme cold, however, we might face excessive loss of heat, which is why body heat production increases through different adaptations, such as:

1) Vascular Adaptation

When we are exposed to cold temperatures, there is a general constriction of blood vessels (namely, a reduction in blood vessels' diameter), in which the flow of blood towards the body's surface is reduced in order to avoid heat loss.

2) Muscle Activity

During extremely cold temperatures, it is fairly common for us to begin to shake involuntarily – a reaction that increases body heat production from skeletal muscles. Similarly, during intense movement, this keeps a constant temperature, even when the ambient temperature is very low (even lower than -25°C and 30°C, approximately).

3) Hormonal Production

Adrenaline and noradrenaline are two "heat producing" hormones emitted in the adrenal medulla, and they increase the production of heat when exposed to cold temperatures. As such, there's an increase in production of thyroid hormone from the thyroid gland, which increases metabolism during rest, therefore generating an extra amount of heat.

1.2.3 Thermoregulation and Heat

During physical exercise, the ability to dissipate heat efficiently is of the utmost importance for the body. For this to be possible, nature has provided us with homeostatic mechanisms that, when activated, either stimulate heat loss or stimulate heat gain, always striving to keep our central temperature within constant values.

Through different physical processes, excess body heat is dissipated into the environment for the purpose of regulating the temperature in the following manner:

1) Heat Loss via Conduction

Exchange by conduction implies a direct transfer of heat from one molecule to another by way of a liquid, solid or gas.

The rate of heat loss via conduction depends on two factors:

- The temperature gradient between the skin and surrounding surfaces.
- The surfaces' thermal characteristics.

For example: when an individual suffering from heat is immersed in cold water, this can generate considerable heat loss. Also, for a person who absorbed high temperatures during his or her exposure to the sun, leaning on a rock in the shade can provide some body heat loss, through thermal conduction between the rock's cold surface and the person's warmer surface. If our body comes into touch with a given object, an exchange of heat will occur between both bodies. The direction of this exchange depends on the heat gradient from the engaged bodies (hot or cold, as we saw in the examples).

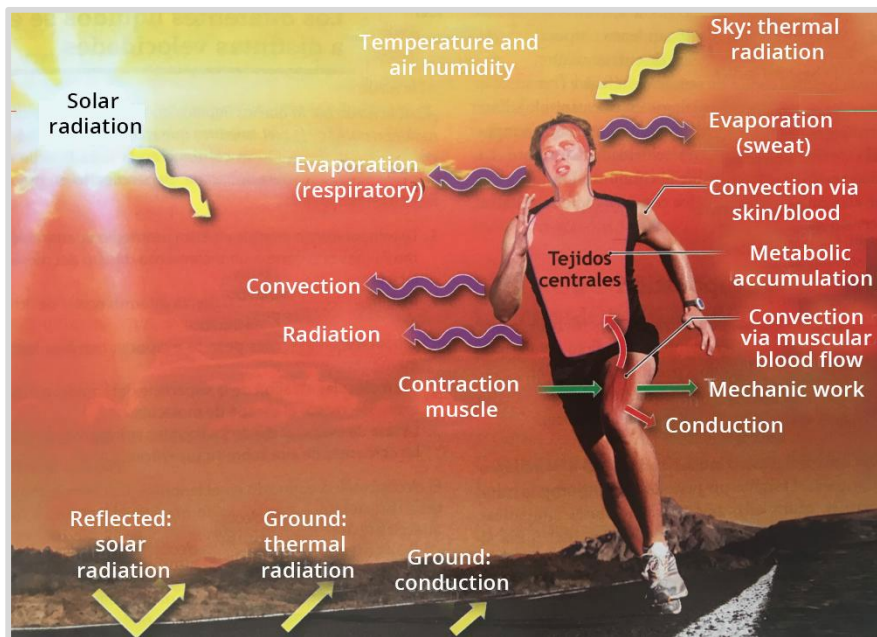
2) Heat Loss via Radiation

All bodies radiate heat through electromagnetic waves, and the sun is the principal radiant source of heat. As long as our body temperature is higher than the ambient temperature, our body will be able to dispose of heat through the mechanism of radiation. The wider the values observed between body temperature (BT) and ambient temperature (AT), the

more effective the mechanism of heat loss via radiation will be.

For example: it is uncommon to sweat when we are resting or when we are in very cold places, precisely because of how effective the mechanism of radiation is, as well as this difference in temperatures.

Figure 5: Heat Production and Transfer



Source: Retrieved from Kach, McArdle & Katch.

3) Heat Loss via Convection

The effectiveness of heat loss via convection will depend on the speed in which air (or water) near the body is exchanged once it has reached a high temperature.

We speak of heat loss via convection when the object makes direct contact with our skin (through air or water). While our body temperature is higher than that of the air or water surrounding us, our body can lose heat through the mechanism of convection, as long as there are water or air currents that continuously replace the air or water directly in contact with our skin.

For example: when we get into a pool with very cold water, the feeling of cold can disappear a little if we stand still for a certain amount of time. What has happened is that our body has become heated through the use of the mechanism of convection, which is to say, the layer of water in direct contact with our body surface. Once you change positions, you feel the cold water once again, because the layer of water that was previously heated has been replaced for a new layer we must now heat by using the convection mechanism.

4) Heat Loss via Evaporation

Water evaporates from the respiratory tract, and the surface of the skin continually transfers heat to the environment.

Each liter of evaporated water extracts approximately 580 kilocalories from the body, and these are then transferred to the environment.

There are three factors that contribute to the total amount of sweat that evaporates through the skin and lung surfaces:

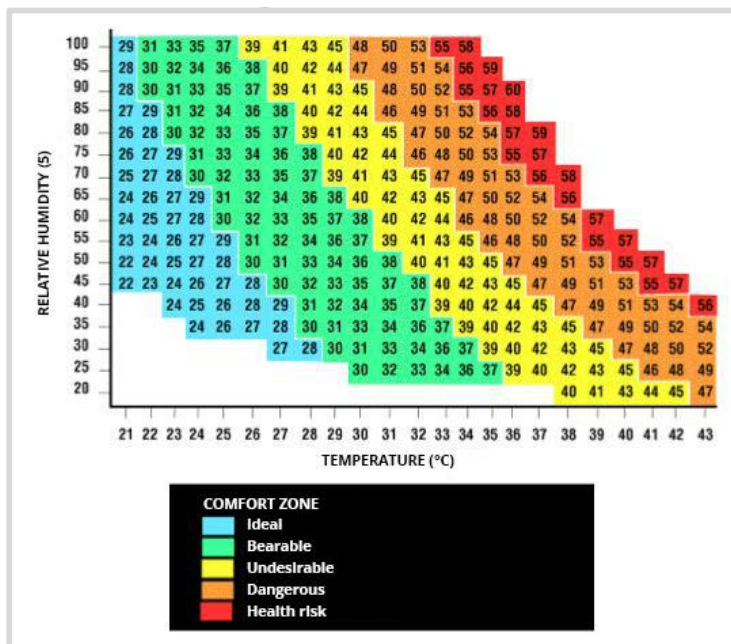
- The surface exposed to the environment.
- The temperature and relative humidity present in ambient air.
- The air convection currents surrounding the body.

In places where the ambient temperature is very high, conduction, convection and radiation are not as efficient in the task of helping the body lose heat. When the ambient temperature is higher than our body temperature, the body gains heat through these three mechanisms of thermal transfer. In this type of environment, or when conduction, convection and radiation cannot dissipate a large metabolic calorie load, the evaporation of sweat – through the skin and respiratory tract – constitutes the only means of dissipating heat. In a general fashion, increases in ambient temperature produce proportional increases in sweat rate.

When it comes to high relative humidity, it is considered the most important factor in determining the efficiency of heat loss via evaporation. This is related to the amount of water present in ambient air at a specific temperature, when compared to the total amount of humidity the air might contain, and it is expressed as a percentage. For example, a relative humidity of 40% would imply that the ambient air is only using 40% of its capacity to carry humidity in the air at that particular temperature. At times of great humidity, the ambient pressure of vapor is closer to that of human skin, around 40 mm Hg. In this scenario, evaporation decreases greatly – even if large amounts of sweat drops are formed on the skin and, finally, these sweat drops begin to run. This kind of perspiration is not a helpful way to lose fluids; it can generate dehydration and overheating, as it creates difficulty.

In Figure 6, we can see the different characteristics of ambient heat, and a few recommendations stemming from it in regards to physical activity and ambient temperature, radiant heat and relative humidity.

Figure 6: Tension-Heat Index



Source: adapted from <http://www.ec.gc.ca>.

1.2.4 Factors that Modify Heat Tolerance

With the understanding that heat is the main generator of significant imbalances during exercise, we will expand on the different factors that interact with the subject's heat tolerance, in relation to the physiological adjustments the body can carry out.

1) Acclimatization

We speak of heat acclimatization when the body produces a series of adaptive physiological changes in order to improve heat tolerance.

During exercise, cutaneous blood flow improves to enable heat transfer from the center to the periphery. This, along with a more effective distribution of cardiac output, also helps stabilize blood pressure during physical activity. This blood flow acclimatization is complemented by a decrease in the threshold of perspiration onset. Therefore, the cooling process begins before central temperature experiences a noticeable increase. The ability to perspire, the most relevant factor in heat acclimatization, increases quickly, and it almost doubles within 10 days of exposure to heat. Sweat also becomes more diluted (with less loss of salt) and is distributed in a more generalized fashion over the surface of the skin, which doesn't seem to happen during exercise training without acclimatization (Hamouti, Del Coso, Ortega & Mora-Rodríguez, 2011).

The largest acclimatization occurs in the first week of exposure to heat, and is completed after 10 days. The process only requires between 2 and 4 hours of daily exposure to heat.

The main benefits of acclimatization are dissipated over the course of two to three weeks following the return to a milder climate.

2) Age

There are ongoing debates regarding the effects of aging on heat tolerance and acclimatization. The most recent studies show that there are some age-related factors that affect the dynamics of thermoregulation, despite the fact that the ability to regulate central temperature during tension heat is similar between young adults and seniors. Aging delays the start of perspiration, and it limits the extent of the perspiration response.

Meanwhile, seniors do not recover from dehydration as easily as young people, due to a reduced thirst reflex. This puts the elderly in a chronic state of dehydration, with plasma volume in lower-than-optimal levels, which can compromise thermoregulation dynamics among seniors.

3) Gender

Both women and men tolerate temperature in the same way when being acclimated in a comparable degree. In these circumstances, both genders acclimate to the same degree.

What should be considered in these cases is that the average woman has a superior external surface per unit of body mass when exposed to the environment, which favors heat dissipation. This refers to a geometric advantage.

In the case of women, menstrual cycle phases must also be considered, as this influences the skin's vascular control that modifies the response to blood flow and perspiration. The latest evidence suggests that, in high temperature and humidity conditions, exercise performance decreases during the luteal phase, perhaps as a consequence to the higher thermal sensibility through the start of activity (Janse de Jonge, 2003).

4) Training Level

A trained individual stores less heat at an early stage during exercise, reaching a stable thermal state and lower internal temperature faster than an untrained individual.

Training increases the sensitivity and capacity to respond to perspiration, which means it is triggered by lower central temperature, which allows the body to produce elevated levels of more-diluted sweat, retaining diverse minerals (Chinevere et al., 2008).

5) Body Fat

Excessive body fat represents a disadvantage when it comes to training at high temperatures.

Fat's specific heat exceeds that of muscular tissue, increasing the capacity of isolating the body's surface, which delays the conduction of heat towards the periphery. Obese and larger individuals also have a lower level of body surface area in proportion to the body mass necessary for effective sweat evaporation, which makes the task even more difficult.

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