Physical activity in the heat: thermoregulation and hydration

Supporting document to the Consensus Statement, Mexico City, February 1999

This document is not intended to be a thorough scientific review, but rather a useful source of information. While it is based on a sound, updated review of the scientific literature, the major intention is to provide clear statements and practical recommendations that are relevant to the Latin American population. The inquisitive reader is directed to recent excellent reviews on this topic [3,4,35,55,89]

Introduction.

Physical activity, structured or not, is becoming a very important aspect of life. It is now widely accepted that physical inactivity is a risk factor for chronic disease and a threat to quality of life [12,24,65]. Millions of people around the world exercise regularly to improve their health, and millions more participate in organized sport. In Latin America, much of this physical activity is carried out in hot and humid conditions, which poses particular challenges to the human body.

People who exercise in the heat face potential problems such as heat illness and impaired performance. During physical activity, muscles generate large amounts of heat that must be dissipated to the environment, or an increase in central (core) temperature will occur. This generation of heat by the muscles is proportional to the work rate, therefore, short-duration, high-intensity exercise (such as 5-10 km fun runs), and longer-duration, lower-intensity activities (such as marathon running) all present a risk. Players in games such as soccer, with many short sprints repeated over a long period, may be at particular risk.

Sweating is a physiological response that attempts to limit the rise in core temperature by placing water on the skin for evaporation, but if this fluid loss is not compensated with ingestion of fluids, temperature regulation, performance, and possibly health, will be impaired. The challenge, therefore, is twofold: to effectively dissipate excess heat to the environment, and to avoid reaching a state of hypohydration.

Consequences of heat stress and dehydration.

The combination of physical activity and heat stress poses a significant challenge to the human cardiovascular system. In addition, whenever fluid loss from sweat is faster than fluid replacement, the individual is in a process of dehydration. Hypohydration modifies many physiological variables during exercise. The direct consequence of hypohydration combined with heat stress is an impaired physical performance, as a result of the inability of the cardiovascular system to maintain the same cardiac output [31]. This fall is a consequence of the reduction in stroke volume, due to a reduced blood volume and lower ventricular filling to a level which cannot be compensated by the increase in heart rate [18]. There is also a linear relationship between the level of hypohydration and body core temperature, because hypohydration impairs thermoregulatory function, making exercise in the heat even more difficult [19].

Hypohydration has a progressively negative impact on exercise performance, even at levels as low as 1% [3,20], 2% [7] or 3% [83] of body weight. It appears that environmental heat stress not only plays an important role *per se* [84], but it also has a potentiating effect on the reduction of maximal aerobic power elicited by hypohydration. Time to fatigue at sub-maximal intensities is also shorter when exercise is performed in the heat. Prolonged aerobic efforts are more likely to be negatively influenced by hypohydration than short-term anaerobic exercise tasks [7]. There are few studies on the effects of hypohydration on anaerobic power, muscular strength, speed, coordination, and agility, and their results are not conclusive.

The negative effect of hypohydration on thermoregulatory function increases the risk of heat exhaustion and heat stroke, two heat-related illnesses [4,34,41]. Heat stroke is a serious condition that may be life-threatening [16], and therefore should be treated immediately by medical personnel, whose major goal will be to lower core temperature [69,91]. Kidney function complications have also been associated with hypohydration and high body core temperatures during exercise in the heat [44,45,86,91,95,97,100]. Finally, a rather common problem are so-called **heat cramps**, or "exercise-associated muscle cramping" (EAMC) [46,50,96]. These "painful spasmodic involuntary contractions of skeletal muscle that occur during or immediately after muscular exercise" [87], are commonly associated with profuse sweating while exercising in the heat, but the scientific evidence supporting the hypothesis of a direct relationship between hypohydration and EAMC is very limited. This issue warrants further investigation.

Effect of the environment on thermoregulation.

As mentioned above, body heat production during exercise is a function of exercise intensity. Dissipation of this heat will depend on heat transfer from body core to skin, on clothing, and on ambient heat stress. The ambient heat stress imposed on an individual is a function of air temperature, wind speed, relative humidity, and solar radiation. A practical combined measure of ambient heat stress is the Wet Bulb Globe Temperature (WBGT) index [26,105]. The American College of Sports Medicine (ACSM) has established guidelines for long-distance runners clad in shorts, T-shirts, and running shoes, in terms of risk of heat illness: if WBGT is above 28° C there is a **very high** risk; when WBGT is between 23 and 28° C the risk is **high**. A WBGT index of 18-23°C indicates a **moderate** risk, and if WBGT < 18° C, the risk is **low** [4]. The risk of heat illness is also higher whenever WBGT is unusually high, relative to the normal climate where people have been exercising.

A large number of Latin American countries are located in the tropical region. While altitude can make a considerable difference (e.g., Mexico City and Bogotá are cooler cities), the tropics are characterized by relatively constant, high temperature and humidity for most of the year. WBGT values higher than 28°C are not uncommon, especially at sea level.

There is preliminary evidence to indicate that inhabitants of tropical regions have a greater tolerance to ambient heat stress, possibly due to their level of chronic heat acclimatization [78,80]. However, until more complete data are published regarding heat stress tolerance of chronically heat-acclimatized people, the ACSM guidelines should be followed.

Heat acclimatization is a collection of physiological adaptations that enable an individual to withstand greater ambient heat stress. It includes an increase in the sweating capacity, a more dilute sweat, and an enhanced ability to sustain a high sweat rate during prolonged exercise [54,88]. All of these adaptations help minimize heat accumulation, allowing a longer endurance time and a lower risk of heat-related illness. Because acclimatized individuals have higher sweat rates, they need to pay more attention to hydration.

Heat acclimatization is a normal result of regular exposure to physical activity in the heat. When athletes or physically active people move or travel to a hotter region, acclimatization can be induced by progressive exposure to heat. At the beginning of the acclimatization process, the duration and intensity of the exercise sessions should be lower than usual. Duration and intensity may be gradually increased every day as heat tolerance improves. Significant adaptations occur within the first 7-14 days of heat exposure [54].

While heat exposure during exercise is very important for acclimatization, it is also true that a higher aerobic fitness *per se* enables individuals to better dissipate the thermal load of exercise, mostly because of an expanded blood volume and an improved sweating capacity [63]. The quantity and quality of exercise needed to improve aerobic fitness is greater than what is recommended for health-related benefits. Frequency should be between 3 and 5 days per week, with a session duration of 20 to 60 minutes, at an exercise intensity of 55/65% to 90% of maximum heart rate [6].

All individuals, acclimatized or not, need to pay attention to climatic conditions and make the appropriate adjustments whenever ambient heat stress is unusually high. Shorter and lighter warm-up sessions prior to training and competition will prevent core temperature from rising unnecessarily. Competition or training strategy should accommodate a lower duration and intensity, together with longer and more frequent breaks, to reduce heat production. Finding cooler areas in the shade or wind for warm-up sessions, breaks, and recovery periods or *siestas* is often possible; this helps keep body temperature lower and prevent dehydration.

Contrary to the recommendations above, it is common in Latin America to see exercising individuals wearing rubber suits or accessories to promote sweating, believing this will result in fat loss. Rubber suits create a microenvironment around the individual where humidity is very high and evaporation of sweat is virtually impossible, severely limiting heat dissipation. Body core temperature increases rapidly, profuse sweating quickly produces dehydration, and fatigue ensues. This procedure is not only useless to facilitate fat loss, it is also a threat to thermoregulation and promotes heat illness.

While it is clear that individuals may adapt to the physiological challenges of physical activity and heat stress by progressively increasing their level of activity and exposure to heat, there is no evidence to show that it is possible to adapt to hypohydration. In fact, hypohydration compromises the advantages of acclimatization. Exercising without drinking may be *muy macho* and strengthen the will, but it hurts the body seriously.

The hydration process.

Euhydration, a normal, balanced level of hydration, is only maintained in physically active people if they ingest enough fluid before, during, and after physical activity. The ability to match fluid loss with fluid intake is limited by the maximal rates of drinking, gastric emptying, and intestinal absorption. Under hot and humid conditions, sweat rates can easily exceed these limits [67].

It has been known for decades that when people exercise and sweat they do not voluntarily replace all the fluid lost through sweating [72,81,94], even when fluids are widely available. This is called voluntary dehydration, and it occurs in unacclimatized children [10,11,102], in acclimatized children [80], and in adults [14,33,81].

Spontaneous fluid intake is influenced by a variety of sensory-related information such as odor, taste, temperature, color, and subjective quality. Only a few of these factors have been studied systematically, the major ones being fluid temperature and flavor. Studies with different fluids show that voluntary fluid intake is maximum when liquids are cool, that is, at a temperature between 15 and 20°C [3,13,98]. Slightly flavored drinks are preferred over plain water, but strong natural flavors like beer, milk, and carbonated drinks are not highly acceptable during exercise [38].

The voluntary consumption of a well-formulated sports drink is greater than that of plain water, in part due to the palatability of sports drinks [37,98,102]. Beverage temperature, sweetness, flavor intensity, mouthfeel, tartness, and aftertaste are all characteristics that influence palatability and thereby encourage or discourage fluid consumption during physical activity. A series of studies with boys exercising in the heat have shown that voluntary intake of a flavored drink was high enough to maintain euhydration, even when sweat rates were high [78,102,103].

Once fluid has been ingested, it must first be emptied from the stomach. Gastric emptying depends on several factors. The exponential nature of the emptying curve indicates the crucial importance of the volume of stomach contents in controlling the emptying rate: as the fluid is emptied and the stomach volume falls, so the rate of emptying is decreased. Maintaining a large fluid volume in the stomach will promote emptying [66,75], although the presence of large volumes in the stomach is not well tolerated by all individuals and is against the preference of many soccer players. This tolerance is subject to training, allowing the individual to handle larger volumes after repeated trials.

Fluids with a greater energy content have slower gastric emptying rates. This pattern is the same during exercise as that observed at rest [39,40,59,62,68,101]. The negative effect of a high energy content on gastric emptying rate is much greater than the effect of a high fluid osmolality. High-intensity exercise will slow down or even stop gastric emptying, but exercise at intensities around 70 to 75% VO_2max has little or no effect on the rate of gastric emptying [36,48,59,71,74]. Severe hypohydration in combination with hyperthermia and intense exercise slows gastric emptying and increases the risk of gastrointestinal distress [73,82].

The third rate-limiting process during hydration is intestinal absorption of fluids. Two major factors governing net water transport in the small intestine are osmolality and solute flux [28,29,90]. Solutions markedly hypertonic to human plasma cause less water absorption and more secretion, while hypotonic solutions promote net water absorption. The addition of carbohydrate to a fluid replacement solution can enhance intestinal absorption of water [29,60,75,90]. The use of multiple substrates (carbohydrates) stimulates several different solute absorption mechanisms, yielding greater water absorption than solutions with only one substrate [90]. The proper amount and type of carbohydrate dramatically stimulates fluid and electrolyte absorption in the small intestine, even in slightly hypertonic drinks.

An adequate hydration **before** physical activity is essential to preserve all physiological functions. Fluid deficit before exercise can potentially compromise thermoregulation, and produce greater cardiovascular strain during the exercise session [3,8,64,83]. Ingestion of 250 to 600 mL of fluids at least two hours before exercise will help assure beginning with a proper hydration level, plus it allows some time for any unnecessary fluid to be released via urine.

There is not enough evidence to support hyperhydration before exercise as a means to improve exercise performance [49,77]. Hyperhydration is difficult to achieve because plasma volume expansion results in hypotonicity and increases diuresis. There is a strong possibility that hyperhydration protocols are simply allowing chronically-hypohydrated subjects to reach a normal level of hydration, a clearly positive physiological achievement that would be meaningless to euhydrated subjects, but is very important in Latin America where cultural influences may promote chronic hypohydration.

During physical activity, the goal of fluid ingestion should be to match fluid loss from sweat or, when sweat rates are too high, to replace as much fluid as possible. This is achieved by drinking small volumes (125 to 500 mL of fluid) regularly, every 15 minutes or so. The amount and frequency need to be adjusted according to particular sweat rates and tolerance of fluid ingestion.

Fluid loss during an exercise session may be estimated by weighing the person nude and dry before and after exercise: approximately 100 mL of sweat were lost for every 100 g of weight loss obtained.

Restoration of water and electrolyte balance is an essential part of the recovery process after exercise that results in sweat loss. Adequate rehydration **after** one exercise session translates into euhydration before the next session. Because of ongoing urine output, subjects are in net negative fluid balance throughout the recovery period, unless the volume ingested exceeds the loss. When the sodium concentration of the ingested fluid is varied (0, 25, 50 or 100 mmol/L) and fluid is ingested in a volume equal to 1.5 times the sweat loss, urine output is inversely proportional to the sodium concentration of the ingested fluid. For effective rehydration, drinks and food should replace electrolytes lost in sweat as well as the volume loss: this means that the intake of sodium should be moderately high (perhaps 50-60 mmol Na^+/L fluid), and there should also be some potassium. To balance this requirement with drink palatability, some of the sodium could be ingested as food. To surmount ongoing obligatory urine losses, the volume consumed should be greater (by at least 50%) than the volume of sweat lost [51,52,53,68,92,93].

Utilization of sports drinks.

Water is a widely available fluid for hydration. While ingestion of water can help offset many problems of dehydration, research conducted over the last five decades has repeatedly confirmed that physically active people can benefit from ingesting a proper mixture of fluid, carbohydrates, and electrolytes. The benefits are proportional to the need for fluid, energy, and minerals of each individual. Physiological efficacy requires that the beverage be formulated to avoid (or to at least minimize) the limitations imposed by voluntary drinking, gastric emptying and intestinal absorption, while providing fluid, carbohydrate, and electrolytes in amounts and at rates known to provoke positive physiological and performance responses [3,17,30,32,47,60,85].

The right amount and types of carbohydrate are important determinants of sports drink efficacy. In addition to imparting the sweetness level that improves palatability, carbohydrate plays a number of other important roles. The proper amount and type of carbohydrate has minimal effect on gastric emptying and yet dramatically stimulates fluid and electrolyte absorption in the small intestine, as mentioned above. The glucose provided by sports drinks is taken up by active muscle cells, helping sustain a high rate of carbohydrate oxidation, which can improve exercise performance. Sports drinks should contain a mixture of carbohydrates (e.g., a combination of sucrose, glucose, and fructose) in a concentration of about 60-70 g/L[61].

Electrolytes play a key role in maintaining fluid intake and promoting rehydration. Fluid intake during physical activity can be maintained by ingesting a small amount of sodium chloride. Absorption of salt into the bloodstream prevents plasma osmolality from dropping below the thirst threshold too quickly and thereby helps preserve the drive to drink. After physical activity, rapid and complete rehydration requires the replacement of the sodium and chloride that was lost in sweat. For these reasons, sports drinks should contain at least 100-mg sodium per 250 ml.

To this date, there is no compelling scientific evidence to support the inclusion of other ingredients in sports drinks. Glycerol, caffeine, certain amino acids, numerous metabolites (e.g., pyruvate, lactate, etc.), and various vitamins and minerals have been suggested as possible ingredients in sports drinks. Although there have been some published reports of purported benefits, there is no scientific agreement that such inclusion would improve sports drink efficacy.

Special population groups.

Exercise and hydration guidelines for physical activity in the heat are generally directed to active adults. Whether they are applicable to healthy children, older adults and pregnant women is an important question since these groups may exercise as much as adults, and they represent a large segment of the population in Latin America. People with common chronic diseases such as hypertension, diabetes mellitus or coronary heart disease may benefit from regular physical activity, but due to the nature of their disease, need special consideration as well. Health professionals are encouraged to study the scientific literature on exercise in specific populations cited below.

Potential thermoregulatory disadvantages of **children** are their lower sweating rate per surface area and per sweat gland, and a higher increase of core temperature as they dehydrate [9]. Despite the lower sweating rate, children may dehydrate as much as adults. When flavored and isotonic sports drinks are available during or after prolonged exercise, the voluntary intake of children is higher [58,78,102], although preliminary evidence suggests this may not be true in heat-acclimatized girls [79]. Coaches and parents have a responsibility to ensure adequate opportunities for fluid intake, to make palatable drinks available, and to encourage drinking before, during and after exercise. About 1.8 $ml\cdot kg^{-1}$ every 15 minutes is enough to keep a healthy child euhydrated during exercise at a moderate intensity in the heat [57]. A higher intake should be considered for acclimatized children, and those living in the tropics who might be chronically hypohydrated.

Much of the heat intolerance of **older adults** is due to their sedentary life, which impairs their aerobic fitness and acclimatization [42]. Independent of the lifestyle, decreased skin blood flow and sweating output were shown to be inevitable changes with aging [43]. When guiding them about exercise in the heat, we should consider their health (including the use of medications), fitness and acclimatization levels. Because of their lower thirst perception for any given degree of hypohydration [56], drinking should be encouraged even if they do not feel thirsty.

Thermoregulatory concerns about exercising during **pregnancy** are related to maternal and fetus responses [15]. Fetal temperature is about 0.5°C higher than that of the mother at rest, so there is a greater risk for baby's hyperthermia during exercise. Hyperthermia may damage fetus growth and formation. After physician clearance and specific advice such as aquatic exercise, a pregnant woman should avoid hypohydration and exercising in hot conditions, to keep her body core temperature below 38.5°C [104]. Fluid replacement may include carbohydrate since hypoglycemia is another concern that may affect growth of the baby and maternal comfort.

Therefore, children, older adults, and pregnant women need extra care to prevent hyperthermia and dehydration. Hydration procedures follow the same basic principles as those for average adults. There is no clinical or physiological reason to contra-indicate utilization of a regular sport drink in these groups, since the composition represents no overload for the body (100 mL of a typical sports drink has about 6 g of carbohydrate, 46 mg Na^+, and 13 mg K^+. This is about half the carbohydrate concentration of many soft drinks and fruit juices, and about the same amount of Na^+ in 100 mL of milk). Because sports drinks are clearly labeled regarding their composition, the amounts can be easily included in the nutritional assessment of individuals. Future studies may indicate if there is an *optimal drink formula* for each particular group.

Hypertension and diabetes mellitus are two common chronic diseases that produce high morbidity and mortality in the world. After seeking for medical advice, the initial treatment of these diseases usually includes nutrition counseling and several lifestyle modifications, such as increased regular physical activity [1,23,25,76]. Basically, the same recommendations for average adults apply to hypertensive and diabetic patients who have no complications, with only a few specific concerns.

It is standard practice to have hypertensive and diabetic patients cleared by a physician for exercise. Physicians and nutritionists should be familiar with the present document and other relevant publications [2,5], and must consider the supply of carbohydrate and sodium in sports drinks when evaluating the diet of their patients.

Diabetic patients should not exercise in extreme temperatures because of potential problems with thermoregulation related to autonomic neuropathies [22,27]. Thermoregulatory responses, including sweating, are often abnormal with different body anhidrotic zones [22], and exercise tolerance is impaired. If carbohydrate content is carefully balanced with the normal diet, sports drinks may be consumed by patients with diabetes to help maintain blood sugar levels during exercise -thus preventing exercise hypoglycemia- and to stay well hydrated. Sports drinks have a high glycemic index, but they normally do not cause or contribute to hyperglycemia during exercise[99]. Individual needs should be determined with the help of a nutritionist or physician.

Hypertensive patients using β-blockers may experience compromised heat dissipation due to reduced skin blood flow, and also an accelerated sweat rate response which could worsen dehydration. Fluid replacement is especially important under these circumstances [21]. Furthermore, diuretic therapy can produce hypokalaemia and hypohydration, but with adequate fluid intake and potassium supplementation, exercise impairment can be avoided [70]. Hypertensive patients under sodium-restricted diets must include the sodium provided by sports drinks into their total intake calculations.

Conclusion.

Scientific evidence shows that regular exercise brings many health benefits, but hot humid conditions pose a major challenge to the body's ability to perform physical activity. Exercise performance is significantly reduced, and the risk of dehydration and heat illness is also increased. Because high heat stress conditions prevail in much of Latin America, a few important strategies are necessary to minimize the impact of these conditions on physically active people and on athletes. These strategies are clearly summarized in the consensus statement attached to this document.

There is a need for further research in the area of physical activity in the heat. The following specific needs have been identified for Latin America:

1. What is the incidence of heat-related illness during sports participation in Latin America? What are the safe limits of WBGT for prolonged physical activity in chronically heat-acclimatized people?

2. What are the risk factors for exercise-associated muscle cramping? Is it possible to reduce the incidence of cramping by maintaining euhydration?

3. Are hyperhydration protocols achieving a true hyperhydration, or simply enabling subjects to overcome chronic hypohydration? What are the physiological and performance benefits or side effects of hyperhydrating athletes before exercise?

4. In the area of sensory characteristics of beverages, there is a need for a multidimensional model of analysis where the relative importance of the different elements can be weighed, and also where dose-response manipulations can be done.

5. Is there a shift on perceptual preferences (e.g., palatability) during exercise related to level of hypohydration, overall fatigue, or sensory fatigue?

6. Besides voluntary fluid ingestion, there is a need to further examine questions about alliesthesia and addiction from both acute and long-term perspectives.

7. Is there a relationship between ingestion of fluids and exercise-related transient abdominal pain (colics)?

8. Is there an optimal sport drink formula specific for children, older adults, pregnant women, or chronically ill people?

9. What are the advantages or disadvantages of sports drink ingestion during physical activity in diabetic or hypertensive patients?

10. Is there a negative effect of hypohydration on motor fitness, as measured by tests of speed, coordination, reaction time, accuracy, and agility? Is this effect in addition to the effect of heat?

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Appendix.

The Wet Bulb Globe Temperature index. This index combines measures of air temperature (Tdb), humidity (Twb) and solar radiation (Tg), according to the equation used by ACSM[4], modified from Yaglou & Minard [105]:

$$WBGT= 0.7\ Twb + 0.2\ Tg + 0.1\ Tdb$$

Because this index uses non-ventilated wet bulb and globe temperatures, that is, the only air movement around the thermometers is due to natural wind speed conditions, this index also includes an indirect measure of the cooling effect of wind.

When black globe temperature is not available, WBGT may be calculated according to Gagge & Nishi: $WBGT = (0.567\ Tdb) + (0.288\ Pa) + 3.38$, where Pa is the water vapor pressure in Torr [26].

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