LESSONS FROM HISTORY

Body cooling and response to heat—a commentary

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The performance of prolonged work or recreational and athletic activities can be compromised by conditions of high heat and humidity.^{1,2} A hot environment reduces convection, conduction, and radiation capacities, thus limiting the body's ability to remove metabolically generated heat. A humid environment intensifies the effects of heat by reducing the capacity for evaporative cooling, the body's main mechanism of heat loss. Heat and humidity combined with physical exertion limit performance by increasing the amount of metabolic heat and by forcing the cardiovascular system to work simultaneously to support both metabolic and thermoregulatory demands for blood flow. If the heat and humidity are sufficiently intense, physical performance may greatly decrease because of the increased need to devote an escalating amount of the cardiac output to the transportation of internal core heat to the periphery, rather than the transportation of oxygen and nutrients to the working muscles.^{1,2} Continued exposure to hot and humid conditions also induces an increase in sweat production. Increased sweating places additional stress on the cardiovascular system if it leads to dehydration. Dehydration can further negatively affect exercise performance by decreasing muscular endurance, maximal aerobic power, and physical work capacity.³

Besides decreased work capacity, prolonged exposure to torrid conditions can generate pathologic states. Heat injury or hyperthermia occurs when these mechanisms fail to restore normal body temperature. Heat injury can take the form of heat cramps, heat syncope, heat exhaustion, and heat stroke.⁴ The mildest form of heat injury is heat cramps. Heat cramps occur when fluid intake is insufficient during heat exposure. Heat syncope occurs when there is excessive pooling of the blood in the extremities. Consequently, the brain does not receive enough blood. Heat syncope usually occurs when a person stops and stands still after working in the heat. In this situation, the person is experiencing peripheral vasodilation to dissipate the heat and, by standing still, is likely to faint. Heat exhaustion is a more serious injury, triggered by excessive sweating and inadequate fluid replacement.

The body is unable to supply the increased blood volume needed by the brain, skin, and muscles in extreme heat, resulting in dizziness, weakness, and fainting. The most serious form of heat injury is life-threatening heatstroke. Heatstroke occurs when the body's sweating mechanism shuts down, the skin becomes hot and dry, and the body is depleted of fluids.

Notwithstanding the deleterious effects of heat and humidity, individuals frequently work, play, or compete in these adverse conditions of their own volition. Because the environmental conditions cannot be changed, the most sensible practice shown to maintain optimal performance and prevent heat injuries has been the prevention of dehydration by constant replenishment of lost fluids. The value of rehydration was shown expertly as early as 1947 in a book entitled *Physiology of Man in the Desert*.⁵ In this book, Adolph et al described the negative impact of dehydration on physiological function, physical performance, and health. Their exhaustive research demonstrated that preventing dehydration by regular ingestion of fluids was indispensable in ensuring the physical and mental well-being of their subjects. Unfortunately, more than 2 decades passed before the value of regular fluid replacement during physical activity was widely recognized and practiced in the athletic setting. During this time, dozens of athletes and military recruits died of hyperthermia complicated by dehydration.⁶

Interestingly, pre-exposure body cooling is another simple practice shown to ameliorate the adverse effects of heat exposure. Yet, pre-exposure body cooling has been almost as slow as consuming fluids to gain acceptance. In 1961, Veghte and Webb⁷ found that prior body cooling with cold air or water immersion increased human tolerance to a high level of heat stress. Their decision to use the altered physiological state of an abnormally low body temperature was based on the natural behavior of the camel. When deprived of water, the camel's body temperature falls below normal during the cool night to compensate for the heat of the desert day. The core of the large body mass then slowly reaches a high temperature during the day, and water is not expended in sweat-

ing. Veghte and Webb⁷ felt that because one notices the summer's heat less after a swim in cool water, a similar process may occur in humans.

Veghte and Webb⁷ compared several experimental conditions: controlled heat exposure, heat exposure preceded by precooling via cold water immersion, and heat exposure preceded by precooling via cool air exposure. Cold water immersion consisted of immersing 5 subjects in a tank of 16°C water for 30, 60, or 90 minutes. For cool air precooling, 3 of the subjects who had participated in the water-cooled experiments underwent 4 cool-air exposures of -1°C air for 30 and 60 minutes, and 7°C air for 60 and 90 minutes. Immediately after both coolings, the subject entered the environmental chamber adjusted to 71°C with a water vapor pressure of 10.5 ± 2 mm Hg and sat quietly until they reached tolerance. Tolerance was determined by allowing the exposure to continue to a clear state of impending heat stroke (ie, a rapidly rising rectal temperature, high pulse rate, diminution of sweating, restlessness, and inability to fix attention). In addition, continuous rectal and skin temperatures, mean body temperatures, heat-storage rates, and initial pseudomotor activity were collected.

Veghte and Webb⁷ found that tolerance to heat was directly related to the body temperature at the start of the heat exposure. In addition, pseudomotor activity was suppressed, and the skin temperature at the initiation of sweating rose as the degree of body cooling increased. Moreover, whenever the precooled rectal temperatures reached the control starting level, the remaining tolerance time was the same as that of the control experiment. Thus, it was concluded that prior body cooling enhanced a person's capacity to withstand a specific high heat load. They surmised that precooling provided this benefit simply by increasing the difference between initial thermoregulatory values and the point of intolerance.

Since this initial report of Veghte and Webb⁷ on resting heat exposure, several other investigations have reported a positive impact of prior cooling upon the body's response to working in a hot environment. In 1970, Falls and Humphrey⁸ found that cold showers (17.8°C) of 3, 6, or 9 minutes resulted in significantly lower heart rates during 5 minutes of exercise at room temperature (21°C–25°C). Falls and Humphrey⁹ showed in a follow-up study that a 10-minute cold shower (14.8°C) before 59 minutes of cycle ergometer exercise at 40.6°C resulted in lower heart rates and rectal temperatures and less sweat loss. Interestingly, in both of these studies, the intervening period between the cold showers and exercise was 10 minutes, suggesting that precooling need not be immediately before the heat exposure. Greater work endurance, enhanced heat storage rate, reduced thermoregulatory strain, and reduced metabolic and cardiovas-

cular stress after precooling have also been reported by other investigators. These benefits have been seen for work in ambient temperatures of 18°C–25°C^{10–13} and in hot, humid conditions.^{14,15} In addition, the transient benefit of precooling during work was demonstrated by Drust et al.¹⁶ In this study, any benefits of precooling were no longer evident at the end of 90 minutes of exercise at 26°C.

Notwithstanding the benefits of increased work endurance, delayed accrual of the critical limiting temperature, increased rate of heat storage, and reduced strain on the metabolic and cardiovascular functions, precooling is not part of any printed recommendations for avoiding heat injuries. Perhaps the lowering of core temperature before heat exposure is considered to be too uncomfortable for an individual, or it may be considered too impractical because of the equipment and time required for a sufficient reduction in core temperature. Nevertheless, the advantages gained from precooling are real and may be worth the extra effort and discomfort. Therefore, it seems prudent that those individuals who counsel and educate people about heat exposure should remember to at least include the basic message of the work of Veghte and Webb,⁷ ie, that the likelihood of experiencing the deleterious effects of heat exposure is reduced if people can reduce their core temperature before the exposure.

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