Living and Training in a Tropical Environment: A Challenge for Aerobic Exercise
Applied Knowledge and Perspectives

O Hue

ABSTRACT

The tropical climate is unique in that the seasons are dominated by the movement of the tropical rain belt, resulting in dry and wet seasons rather than the four-seasonal pattern of changes in temperature and day length seen in other parts of the world. Humid tropics are characterized by consistently high monthly temperatures, often exceeding 18°C throughout the year, and rainfall that exceeds evapotranspiration for at least 270 days per year. Although considerable information has been gathered on the physiological adaptation to hot/dry climates, data on acclimation to hot/humid climates are still limited.
This review focusses on the effects of the tropical environment on human exercise performance through studies performed in the Caribbean, with a special emphasis on prolonged aerobic exercise such as swimming, cycling and running.

Keywords: Acclimatation, cycling, running, swimming

Vivir y Entrenar en un Ambiente Tropical: un Reto para las Perspectivas y los Conocimientos
Aplicados en Relación con el Ejercicio Aeróbico

O Hue

RESUMEN

El clima tropical es único en el sentido de que las estaciones están dominadas por el movimiento del cinturón de lluvias tropicales, que trae como consecuencias estaciones de seca y lluvia, antes que el patrón de cuatro estaciones que produce los cambios de temperatura y duración del día, observados en otras partes del mundo. Los trópicos húmedos se caracterizan por temperaturas mensuales consistentemente altas, que a menudo exceden 18°C a lo largo del año, y precipitaciones que exceden la evapotranspiración durante por lo menos 270 días en el año. Aunque se ha reunido considerable información sobre la adaptación fisiológica a los climas cálidos y secos, los datos sobre la aclimatación a los climas calientes y húmedos, son todavía limitados.
Esta revisión se centra en los efectos del ambiente tropical sobre el rendimiento de los ejercicios humanos a través de estudios realizados en el Caribe, con un énfasis especial en ejercicios aeróbicos prolongados, tales como la natación, el ciclismo, y la carrera.

Palabras claves: Aclimatación, ciclismo, carrera, natación

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INTRODUCTION

The specificity of the tropical (*ie*, hot/humid) environment is the high degree of humidity that does not permit adequate evaporation. Thus, when the environmental evaporative capacity is limited, adherence to the strategy used in a hot/dry climate (*ie* reducing heat storage by increasing the sweating rate) creates a physiological disadvantage (1) that results in severe dehydration. The only way to achieve a match between heat gain and heat dissipation during outdoor exercise is by reducing the metabolic heat production, thus the intensity.

Swimming

The thermal balance of swimmers is regularly challenged because of the high heat transfer coefficient of water (2). Al-

From: Laboratoire Actes, UFR-STAPS, Universitè des Antilles et de la Guyane, Campus de Fouilloole, 97139 Pointe à Pitre, Guadelope, France.

Correspondence: Dr O Hue, Laboratoire Actes, UFR-STAPS, Universitè des Antilles et de la Guyane, Campus de Fouilloole, 97139 Pointe à Pitre, Guadelope, France. E-mail: oliver.hue@univ-ag.fr.

though most studies have reported the effect of cold water on thermoregulation, swimming in high temperature has demonstrated increased heart rate, skin circulation and oesophageal temperature to the same extent as running in a hot environment (3). We recently demonstrated that the aerobic performance of young competitive swimmers was affected by the combination of the high convection and conduction capacity of water and the use of the silicone swim cap (SC) usually worn for training and competition. These youngsters swam in a 33˚C swimming pool in hot/humid climate (29.2˚C and 74% rh) and the results indicated that swimming with SC on the head could be a stress for the central command of sudation, *ie* the hypothalamus, which is particularly sensitive in children (4). We concluded that physiological limitations had occurred and long distance swim performance was curtailed in these children. Because thermoregulation during training sessions may decrease training intensities and thereby have a negative effect on future performance in competition, we therefore recommended that young competitive swimmers and their coaches envisage removing the SC during training sessions and competitions of 800-m or more in a tropical environment.

Cycling

Prolonged submaximal cycling performance is greatly decreased by dehydration and/or hyperthermia in the laboratory (5), in which convective and evaporative cooling is likely to be less than that encountered in outdoor competition. In outdoor conditions, elite cyclists ride at speeds ranging from 20 to 50 km.h-1, which generate an equivalent facing windspeed that normally allows for enough thermoregulation. Saunders *et al* (6) compared cycling at different air velocities in the laboratory in warm and humid conditions and demonstrated that when air velocity is 33 km.h-1 or higher, the evaporative capacity of the environment increases proportionately so that excess heat is reduced. These conclusions were corroborated by our group (7) during the Tour of Guadeloupe (a 9-day cycling race; mean conditions: 31˚C and 76% rh) for which we demonstrated that the physiological parameters (*ie* mean heart rate, lactate response) and performances (*ie* average speed) did not differ from those recorded during similar events performed in neutral conditions. These findings highlight the positive effects of high convection (linked to high cycling velocity) in tropical climates.

Running

As running speeds are lower than cycling speeds, the effect of air convection is of less importance. Heat production in running has been described as depending on (*ie* increasing with) the athlete's body mass and speed (8), and in prolonged running events such as the marathon, thermoregulation can be a problem. Because heat production in running depends on body mass and especially muscle mass (*ie* muscle producing most of the heat during exercise) and heat loss depends on surface area, an athlete's body mass has an approximately two-fold greater effect on heat production than on heat dissipation (9). Running speed also increases heat production more than heat dissipation, and while heat production depends on absolute running speed, heat exchange by convection and evaporation is determined by the square root of the velocity of air flow over the skin (9). In fact, in hot/humid climates with heat dissipation mechanisms at their limits, runners with lower body mass have a distinct thermal advantage: producing and storing less heat at the same running speed, they can run faster or farther before reaching a limiting rectal temperature (10). Notwithstanding the ethnic difference, Marino *et al* (11) demonstrated better performances in African runners (*ie* with smaller body size) than Caucasians (*ie* with greater body size) in warm and humid but not in cool environmental conditions, with both populations being equally acclimated.

Adaptation to hot and humid climate when exercising

Case of acclimated versus unacclimated individuals

Heat acclimation (HA) refers to an increase in heat tolerance while working or exercising under stress conditions (12). The physiological adaptations of HA include increased cardiac output, stroke volume, sweat rate and blood plasma volume; decreased heart rate (HR), core, rectal and mean skin temperature at rest (13); and increased oxygen consumption at a given work rate along with earlier sweating during exercise (12). Although some of the processes have been demonstrated to also occur within 8 and 14 days in tropical climates (14, 15), the full acclimation expected by athletes (*ie* to be able to reproduce the same performance in a stressful climate after acclimation as in neutral environment) has failed to become a reality.

We demonstrated significantly lower performance during a maximal incremental outdoor running test in high-level triathletes (coming from temperate climate) after 8 and 14 days of acclimation in tropical climates (14, 15) putting into evidence the difficulty of fully acclimating to the tropical environment. The subjects of the studies were well-trained, had high VO2max, and trained for more than two hours per day in the tropical climate (*ie* they trained for 4 h.day-1, the same training schedule as in neutral climate), which are the three characteristics reported to facilitate the acclimation process (16, 17) .

Some authors have demonstrated that acclimated individuals (*ie* people native to or having lived in a tropical climate for at least two years) better thermoregulate with suppressed sweating (18), which provides the advantage of preserving body fluid and osmoregulation. However, this adaptation was demonstrated to be insufficient during prolonged exercise at high intensity. Saat *et al* (19) demonstrated that subjects, or natives acclimated to tropical climates, had lower sudation and higher skin temperature (*ie* resulting in higher vapour pressure at the skin surface, thus improving evaporation) and rectal temperature at 40% VO2max, but Voltaire *et al* (20) demonstrated that natives to tropical climates had significantly lower one-hour cycling performance at 80% HRmax in tropical than in neutral climate.

Sex and/or anthropometric effects

The advantages of smaller body mass when distance running in warm and humid conditions have been demonstrated (9). The impact of the body surface area/mass ratio suggests that women are in a better situation to thermoregulate in hot/humid climate. Normally, men display better thermoregulation capacity due to a faster sweat rate and a larger body mass, enabling greater heat accumulation. In hot/humid climate, however, they are unable to benefit from their higher sweat rate because of the reduced evaporative capacity of humid air. In fact, their greater sweat loss induces dehydration and a consequent loss in exercise performance.

Training prescription in hot and humid environment

Testing in a climatized laboratory versus training in hot and humid conditions?

Target HR recommendations are often based on the results of laboratory exercise tests performed in climatized rooms. Ventilatory thresholds, determined during progressive exercise testing, are important predictors of both performance and training recommendations in endurance exercise (21). Thus, determination of the specific HR associated with these thresholds is of great use in prescribing adequate training loads based on HR data.

During exercise in a hot/humid environment, both dehydration and hyperthermia occur rapidly, affecting the cardiovascular system: the fluid loss by sweating induces an HR drift that could disturb the relationships between HR and ventilatory thresholds. Hyperthermia has a direct effect on ventilation (22) and a direct effect of increased core temperature has been hypothesized to cause a change in the equilibrium constants of the CO_2 buffer system, resulting in a diminished capacity to buffer CO_2 by body fluids (23). Therefore, testing athletes in a climatized laboratory could yield data that cannot be generalized to training in a tropical environment. We recently conducted a study to determine whether ventilator thresholds are similar in tropical and neutral conditions in Guadeloupean elite cyclists performing a maximal cycling test (24). We observed that hyperthermia occurred in the tropical condition without significant difference between the two conditions regarding the parameters usually used to prescribe training loads. That suggests that testing cyclists in a climatized laboratory will yield good information for training prescription in tropical climate.

Optimization of performance in hot and humid Environment

Because the hot/humid environment decreases performance if no convection is available, athletes who plan to compete in this climate need to be well advised. First, well-trained subjects acclimate better than less trained subjects (16). Secondly, if 14 days is not sufficient to reach the same performance level as in a neutral climate, a physiological process occurs between 8 and 14 days that increases thermoregulation (14, 15). Thirdly, two hours of daily training facilitates the acclimation process (17) and, lastly, hyperthermia and dehydration are worse than hyperthermia alone (25). Thus, a well-trained athlete with high aerobic capacity, arriving in the hot/humid climate at least 10 days before the sporting event and willing to hydrate as recommended (25), could certainly perform optimally, despite the insurmountable deleterious effects of the hot and humid climate on prolonged sporting performance.

PERSPECTIVES

Training in a tropical climate to increase performance in neutral climate

Training in a tropical climate in order to optimize performance in a neutral climate seems to be as interesting as training at an altitude. Hypervolaemia is one of the most important (and performance-related) adaptations that occurs during aerobic exercise (26) and relative humidity is the most important factor of environmental stress (27). It induces a high level of sweating, which lowers heart rate and internal body temperature in relation with hypervolaemia. We have demonstrated the positive effect (*ie* a 10% increase in performance in 400-m front crawl swimming) of eight days of training in tropical climate for high-level swimmers (28). However, similar to the observations for altitude training, the decay of acclimation to tropical climate is variable (17) and should thus be carefully studied.

REFERENCES

1. Shapiro Y, Moran D, Epstein Y. Acclimatization strategies—preparing for exercise in the heat. Int J Sports Med 1998; **19:** (**Suppl 2**) S161–3.
2. Wade CE, Veghte JH. Thermographic evaluation of the relative heat loss by area in man after swimming. Aviat Space Environ Med 1977; **48:** 16–18.
3. Holmér I, Bergh U. Metabolic and thermal response to swimming in water at varying temperatures. J Appl Physiol 1974; **37:** 702–5.
4. Meyer F, Bar-Or O, MacDougall D, Heigenhauser GJ. Sweat electrolyte loss during exercise in the heat: effects of gender and maturation. Med Sci Sports Exerc 1992; **24:** 776–81.
5. Montain SJ, Coyle EF. Influence of the timing of fluid ingestion on temperature regulation during exercise. J Appl Physiol 1993; **75:** 688–95.
6. Saunders AG, Dugas JP, Tucker R, Lambert MI, Noakes TD. The effects of different air velocities on heat storage and body temperature in humans cycling in a hot, humid environment. Acta Physiol Scand 2005; **183:** 241–55.
7. Hue O, Voltaire B, Hertogh C, Blonc S. Heart rate, thermoregulatory and humoral responses during a 9-day cycle race in a hot and humid climate. Int J Sports Med 2006; **27:** 690–6.
8. Nielsen B. Olympics in Atlanta: a fight against physics. Med Sci Sports Exerc 1996; **28:** 665–8.
9. Dennis SC, Noakes TD. Advantages of a smaller body mass in humans when distance-running in warm, humid conditions. Eur J Appl Physiol Occup Physiol 1999; **79:** 280–4.
10. Marino FE, Mbambo Z, Kortekaas E, Wilson G, Lambert MI, Noakes TD et al. Advantages of smaller body mass during distance running in warm, humid environments. Pflugers Arch 2000; **441:** 359–67.
11. Marino FE, Lambert MI, Noakes TD. Superior performance of African runners in warm humid but not in cool environmental conditions. J Appl Physiol 2004; **96:** 124–30.
12. Armstrong LE, Maresh CM. The induction and decay of heat acclimatisation in trained athletes. Sports Med 1991; **12:** 302–12.
13. Wyndham CH, Rogers GG, Senay LC, Mitchell D. Acclimization in a hot, humid environment: cardiovascular adjustments. J Appl Physiol 1976; **40:** 779–85.

14. Hue O, Voltaire B, Galy O, Coste O, Callis A, Hertogh et al. Effects of 8 days acclimation on biological and performance response in a tropical climate. J Sports Med Phys Fitness 2004; **44:** 30–7.
15. Voltaire B, Galy O, Costes O, Racinais S, Blonc S, Hertogh C et al. Effect of fourteen days of acclimatization on athletic performance in tropical climate. Can J Appl Physiol 2002; **27:** 551–62.
16. Lind AR, Bass DE. Optimal exposure time for development of acclimatization to heat. Fed Proc 1963; **22:** 704–8.
17. Pandolf KB, Burse RL, Goldman RF. Role of physical fitness in heat acclimatisation, decay and reinduction. Ergonomics 1977; **20:** 399–408.
18. Bae JS, Lee JB, Matsumoto T, Othman T, Min YK, Yang HM. Prolonged residence of temperate natives in the tropics produces a suppression of sweating. Pflugers Arch 2006; **453:** 67–72.
19. Saat M, Sirisinghe RG, Singh R, Tochihara Y. Effects of short-term exercise in the heat on thermoregulation, blood parameters, sweat secretion and sweat composition of tropic-dwelling subjects. J Physiol Anthropol Appl Human Sci 2005; **24:** 541–9.
20. Voltaire B, Berthouze-Aranda S, Hue O. Influence of a hot/wet environment on exercise performance in natives to tropical climate. J Sports Med Phys Fitness 2003; **43:** 306–11.
21. Luciá A, Hoyos J, Carvajal A, Chicharro JL. Heart rate response to professional road cycling: the Tour de France. Int J Sports Med 1999; **20:** 167–72.
22. White MD, Cabanac M. Exercise hyperpnea and hyperthermia in humans. J Appl Physiol 1996; **81:** 1249–54.
23. Stadie WC, Austin JH, Robinson HW. The effect of temperature on the acid-base protein equilibrium and its influence on the CO2 absorption curve on whole blood, true and separated serum. J Biol Chem 1925; **66:** 901.
24. Hue O, Antoine-Jonville S, Galy O, Blonc S. Maximal oxygen uptake, ventilator thresholds and mechanical power during cycling in tropical climate in Guadeloupean elite cyclists. J Sci Med Sport 2010; **13:** 607–12.
25. Sawka MN, Noakes TD. Does dehydration impair exercise performance? Med Sci Sports Exerc 2007; **39:** 1209–17.
26. Brun JF, Khaled S, Raynaud E, Bouix D, Micallef JP, Orsetti A. The triphasic effects of exercise on blood rheology: which relevance to physiology and pathophysiology? Clin Hemorheol Microcirc 1998; **19:** 89–104.
27. Gleeson M. Temperature regulation during exercise. Int J Sports Med 1998; **19:** (**Suppl 2)** S96–9.
28. Hue O, Antoine-Jonville S, Sara F. The effect of 8 days of training in tropical environment on performance in neutral climate in swimmers. Int J Sports Med 2007; **28:** 48–52.