How humans adapt to exercising and working in the tropics

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Abstract
Human migration to Australia occurred over 62,000 years ago. Those first Australians established one of the oldest continuous populations on the driest of the inhabited continents, surviving the world's longest drought (>10,000 y). Indeed, the traditional owners established a cultural identity and sustainable lifestyle thousands of years before any of the more recognised ancient civilisations. However, our temperature and rainfall variations belie the national stereotype, with temperatures from -23°C (Charlotte Pass, New South Wales) to 50.7°C (Oodnadatta, South Australia), and annual rainfalls from 125 mm (Lake Eyre, South Australia) through to 12,461 mm in the tropical north-east (Bellenden Ker, Queensland). Those climates shaped the variability, quality and quantity of the flora and fauna, and provided unique and diverse adaptation opportunities that influenced the cultural, lifestyle and physiological characteristics of the Aborigines.

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How humans adapt to exercising and working in the tropics

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Introduction: our heritage

Human migration to Australia occurred over 62,000 years ago. Those first Australians established one of the oldest continuous populations on the driest of the inhabited continents, surviving the world’s longest drought (>10,000 y). Indeed, the traditional owners established a cultural identity and sustainable lifestyle thousands of years before any of the more recognised ancient civilisations. However, our temperature and rainfall variations belie the national stereotype, with temperatures from -23°C (Charlotte Pass, New South Wales) to 50.7°C (Oodnadatta, South Australia), and annual rainfalls from 125 mm (Lake Eyre, South Australia) through to 12,461 mm in the tropical north-east (Bellenden Ker, Queensland). Those climates shaped the variability, quality and quantity of the flora and fauna, and provided unique and diverse adaptation opportunities that influenced the cultural, lifestyle and physiological characteristics of the Aborigines.

Until the first European settlements (1788), the traditional owners lived in isolation. The early settlements in Sydney Cove were soon extended to the mostly temperate, coastal climates of Norfolk Island, Tasmania, Port Macquarie and Moreton Bay. However, free settlers rapidly spread across the continent, and following Federation (1901), Australia’s first medical research institute was established (1908): the Australian Institute for Tropical Medicine (now at James Cook University). One of its founding objectives was to evaluate the physiological consequences of the Immigration Restriction Act (1901; the white Australia policy), the outcome of which was that Europeans had to perform physically demanding jobs in tropical climates, resulting in significant heat-illness. The first directors of that institute (A. Breinl [1908-1920] and R.W. Cilento [1922-1928]) were perhaps Australia’s first human, thermal physiologists⁴. The foundation for this presentation will be set upon this combined heritage, with the principal objective being to provide insights into thermal adaptation in the tropics⁴.

The problem with the tropics

From a climatic perspective, it is the air temperature and water vapour pressure that present the greatest challenges. Thermal physiologists determine the likely physiological impact of environmental conditions using rational heat-strain scales that are based on the First Law of Thermodynamics. One such derivation is the Heat-Strain Index³, which can be used to quantify the compensability of working conditions. For instance, for individuals performing 100 W of external work with 65% of the skin uncovered, in an air temperature of 35°C and a water vapour pressure of 4.78 kPa (relative humidity 85%), the heat-strain quotient will be 1.674. Since values >100 are considered uncompensable, moderate-hard physical work is prohibitive in these conditions for the unadapted, leading to unregulated (forced) hyperthermia, and eventually to heat illness.

Ethnic differences: Aboriginal and tropical residents

Physiological adaptation is almost invariably associated with a reduced (blunted) sensitivity of the effector responses to a given stimulus, and thereby reducing physiological strain during subsequent stress exposures. A classical example is the blunted or habituated metabolic reaction of the traditional-living Aborigines to cold stress, relative to non-adapted Caucasians⁵, although we know little about their tropical-heat tolerance. In this regard, more is known about the thermal adaptation of our Asian neighbours³⁴, with apparent ethnic differences not reflecting inherited (genotypic) variations, but acquired (phenotypic) adaptations, that increase heat tolerance and elevate the safety margin during thermal-stress loading.

The progression from “mad dogs” to “permanent summermen” is triphasic in nature⁴⁵ in both tropical indigenes and Europeans, although most short-term, heat-adaptation research was not continued through to the final phase, leading to some misinterpretation of the available evidence. The acute response phase is characterised by work intolerance, with a significantly elevated risk of heat illness (phase one). This intolerance is, however, most frequently expressed in the form of cardiovascular insufficiency; a failure to adequately regulate blood pressure⁴. With repeated heat exposure, healthy individuals elevate their autonomic heat-loss responses (phase two). This is most apparent for sudomotor function, which reveals a lower sweat onset threshold, a greater sensitivity and an elevated peak secretion rate. However, several cardiovascular adaptations precede, and even facilitate, sudomotor adaptation. For instance, the plasma volume is elevated to buffer against both sweat losses and the obligatory cutaneous vasodilatation. In most
climates, but particularly within humid-heat, profuse sweating is ineffective and wasteful. Therefore, within both indigenes and other long-term tropical residents, one finds clear evidence of sudomotor habituation (phase three), with much less prolific sweating in the heat.

**Integrated thermal adaptation**

The primary functional adaptations to repeated humid-heat exposure are designed to support both thermal and cardiovascular homeostasis when exposed to the heat. Those mechanisms of adaptation will be developed in detail within this presentation, and will include changes within body-fluid balance, central cardiac function, peripheral vasomotor responses, heat production, sudorific function and deep-body temperatures. The possibility of morphological adaptation will also be introduced. As an entrée to those discussions, adaptation theory will be described, as an understanding of those concepts is essential to both the experimental and practical application of heat adaptation. That discussion will include the following topics: physiological overload, adaptation thresholds, the adaptation impulse, adaptation forcing functions and their progression, adaptation specificity and adaptation decay.

**The practices of heat adaptation**

Several methods for inducing heat adaptation will be presented, including their historical development. Whilst pure physiologists wish to emphasise the mechanisms of adaptation, applied scientists have more pragmatic interests, such as the preparation of workers and athletes to tolerate known working and climatic conditions. These need not be mutually exclusive objectives, but previous and repeated failure to differentiate between those purposes has led to both an over-simplification and misinterpretation of the scientific evidence. Two heat-adaptation practices will be explored in detail: the traditional (constant stress) model and the controlled hyperthermia (constant strain or isothermal) method. For workers (e.g., military and emergency service personnel), the former method is acceptable and most commonly used, but for investigating the mechanism of thermal adaptation and for the preparation of athletes, the latter method is recommended, although that approach has infrequently been adopted.

**Adaptation avoidance**

Finally, it is curious to observe that, within a century, we have moved from a position of seeking knowledge concerning the enhancement of human heat tolerance through stress exposure and adaptation, to an endemic state of strain minimisation, with an almost complete prevention of stressful exposures in some individuals. Yet, over many thousands of years, repeated encounters with a broad array of internal and external stresses led to the acquisition of the broadly adapted state in humans; biological generalists. Those attributes were relayed to succeeding generations, either epigenetically or through natural selection. However, many contemporary behavioural practices in the home and at work now prevent people from experiencing the stresses that would have ensured their survival during another era. Since those adaptions, or the lack thereof, can be transferred epigenetically to the next generation, one wonders how modern, first-world humans may survive within less pleasant circumstances.

**Conclusion**

A unifying theme within this communication will be adaptation specificity. That is, the nature of the adaptation stimulus will largely dictate the form of the resulting physiological adaptation and its transference to, and protection from, other stresses. This is true for all who live, work and play in hot-humid regions. It is perhaps more pertinent to the participants of heat-adaptation research and those who undertake heat adaptation to reduce occupational strain or to enhance athletic performance. It is both fitting and relevant to conclude with a quote from another past scientist:

“It is conceivable that individuals may not be all alike in their choice of the acclimatization mechanisms which nature has placed at their disposal.”

**References**