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Heat: a primer for public health researchers

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ABSTRACT

Objectives: To provide a primer on the physical characteristics of heat from a biometeorological perspective for those interested in the epidemiology of extreme heat.
Study design: A literature search design was used.
Methods: A review of the concepts of heat, heat stress and human heat balance was conducted using Web of Sciences, Scopus and PubMed.
Results: Heat, as recognised in the field of human biometeorology, is a complex phenomenon resulting from the synergistic effects of air temperature, humidity and ventilation levels, radiation loads and metabolic activity. Heat should therefore not be conflated with high temperatures. A range of empirical, direct and rational heat stress indices have been developed to assess heat stress.
Conclusion: The conceptualisation of heat stress is best described with reference to the human heat balance which describes the various avenues for heat gain to and heat loss from the body. Air temperature alone is seldom the reason for heat stress and thus heat-related health effects.

Introduction

The human body deals with a range of atmospheric stressors including heat, environmental radiation and air pollution. Either singularly, or in combination, these may affect the physiological and/or psychological well-being of an individual on a range of time scales. Notwithstanding the importance of environmental radiation or air pollution, heat has become an increasing challenge for public health as demonstrated by the occurrence of major fatal extreme temperature events in many countries.[1] Added to this is the spectre of an increased frequency of extreme heat events related to human-induced climate change;[2] worryingly, there is mounting evidence that some recent public health significant heat events can be partly attributable to human-related increases in global temperatures.[3–5]

There is a burgeoning literature on the health impacts of heat and its management.[1] However more often than not, and perhaps implicitly rather than explicitly, heat-health studies outside the discipline of human biometeorology[6] frequently assume 'heat' to mean 'high temperature', even though heat as a physical term is a complex phenomenon resulting from the interactions of a range of environmental variables. Given this, the purpose of this article is to provide a primer, from a human biometeorological perspective, on the nature of heat in a human health context. Accordingly, this paper is organised as follows: What is heat in a health context? defines heat; Human heat balance introduces and describes the concept of the human heat balance (HHB); Assessment of heat stress

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details common methods for assessing levels of heat stress, including those classified as empirical, direct and rational; Conclusions outlines the conclusions and public health importance. As this article only provides a primer on heat, a systematic review of the literature on heat and health is not be presented here. Rather, this primer defaults to the related papers in this special issue for more detail on the impacts and management of heat as a public health issue.

What is heat in a health context?

Although heat and temperature are often conflated to mean the same thing, in strict definitional terms, heat and temperature are different as summarised in Table 1. Heat is energy in the process of being transferred from one substance or object to another (moving from hot to cold). Following its transfer, heat is stored as internal energy in the receiving object. A change in the level of stored energy can be recorded in the form of a temperature change. In a human health context, as explained more fully in the next section, energy or heat can be transferred to the human body from the surrounding environment by conduction, convection and radiation. Therefore, a rise in body core temperature (BCT) occurs if the environment imposes significant heat gain on the human body that cannot be offset by heat loss (e.g. evaporation).[7]

Heat stress is a common term used in heat and health studies. In human health terms, heat stress is the negative effect of the thermal energy (heat) environment on an individual. As a response to heat stress, the body exhibits strain (see Fig. 1), which describes actions the body undergoes in responding to the increased heat load (e.g. increased skin or core temperature).[8] However, heat strain in the form of rising skin temperature and sweat rate will precede a rise in BCT (indicative of heat stress), and when the BCT does begin to rise, it is often environmentally driven.[9] While most thermal energy resulting in heat stress transfers from the surrounding environment, excessive physical activity in warm-hot environments can produce what is known as exertional heat stress or illness[10] through the heat produced by metabolic activity. When combined with external heat stress, major heat strain can manifest by a rapidly rising BCT and a range of heat illnesses which, in increasing order of severity, are heat rash, heat oedema, heat syncope, heat cramps, heat exhaustion and life-threatening heatstroke.

The main components influencing external heat gains are atmospheric temperature, radiation, wind speed (ventilation) and humidity. Air temperature is important because it reflects the level of heat in the air resulting from sensible heat transfer (i.e. transfer of energy as heat without a phase change) mainly from the earth's surface into the lower layers of the atmosphere, although in urban environments sensible, heat transfer from vertical surfaces is also important. As described by Davis et al.,[11] humidity may play one of two roles as a component of heat stress. First, low levels of atmospheric moisture can facilitate high evaporative losses from the skin surface, which facilitates body cooling. However, uncontrolled rates of sweating may lead to life-threatening dehydration and the halt of sweating, which can also drive up BCT. Alternatively, high levels of atmospheric moisture may inhibit evaporation rates thus rendering the sweating process impotent as a heat loss mechanism (also termed ‘inefficient sweating’). With respect to public health, individuals who are young, old, sick and/or on medication may have compromised sweating and/or thirst response, and thus require increased monitoring during heat events.[12,13] Ventilation, a product of wind speed or atmospheric turbulence, normally helps to remove heat from the body by turbulent heat transfer. This type of heat loss occurs when the air temperature is less than skin temperature (which normally remains around 36 °C). Yet when air temperature rises above that of skin, ventilation adds heat to the body *via* convection. High (low) rates of

Table 1 – Basic differences between heat and temperature.

	Heat	Temperature
Definition[a]	Heat is the energy contained within a substance. It represents the total energy of all the molecular motion (kinetic energy) in a substance or object. The hotter the substance or object the faster the molecular motion and the greater the heat contained within	Temperature is a measure of the average heat or thermal energy of the molecules making up a substance or object. It is expressed by one of several arbitrary scales such as Celsius or Fahrenheit. How ‘hot’ or ‘cold’ a substance is depends on how fast the atoms comprising that substance are moving
Units	Joule	Celsius, Fahrenheit, Kelvin
SI unit	Joule	Kelvin
Flow	Heat can be transferred or flow from one location to another if there is a difference in temperature (e.g. skin-to-air temperature). Heat flows are referred to as fluxes and measured in Watts (equivalent to 1 J/sec). In biometeorology and meteorology, heat flux densities are usually encountered in the literature – expressed as W/m^2	Temperature does not flow, rather temperature differences or temperature gradients (e.g. °C/m) determine the direction and magnitude of heat flow. Greater movement of heat towards the human body will therefore occur when the temperature difference between two objects (e.g. human body and environment) have a large temperature contrast
Ability to do ‘work’	Heat possesses the ability to do work	Temperature does not work, rather it measures the degree of heat

[a] The American Meteorological Society point out some of the confusion associated with heat as captured in its glossary entry for this term as follows: ‘*Heat, used as a noun, is confusing and controversial in its scientific meaning. The differential of heat is considered imperfect in that its value depends on the process applied. In the thermodynamic definitions in this glossary, heat is avoided as a noun or adjective except where required by established use. The process of heating is, however, defined as the net absorption of internal energy by a system.*’ (http://glossary.ametsoc.org/wiki/Heat).

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