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Human Health and Physical Activity During Heat Exposure

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Preface

Environmental heat stress does not discriminate between those that are affected, even afflicting seemingly healthy and active individuals such as those observed in athletic, occupational, and military settings. In fact, these individuals are exposed to unique circumstances where exposure to extreme heat may be inevitable (e.g., outdoor work and external radiant heat sources) and self-regulation of work is challenging. This raised the need for governing organizations to create strategies to mitigate adverse health events, improve methods to safeguard their respective persons that they oversee, and integrate the fundamental concepts in human thermal physiology into their respective fields to optimize the working environment. In recent years, the assessment of extreme heat risk has morphed into a larger, common concern across multiple fields of science, including medicine, physiology, public health, biometeorology, and environmental science. This creates an opportunity to foster an interdisciplinary network of experts, allowing for a more comprehensive approach in examining the impact of extreme heat on one's health during physical activity.

This book is one of our initial steps in connecting the parallels we have observed across disciplines, and it is our hope that the topics covered in the book – human physiology, climatology, epidemiology, population-specific special considerations, and behavioral and technological adjustments – regarding extreme heat, will further facilitate interdisciplinary collaboration to enhance the health and safety of all who are impacted by extreme heat.

Storrs, CT, USA Yuri Hosokawa

Acknowledgments

The vision to compose a book about the risk of extreme heat in the context of physical activity originated from an inaugural meeting in 2016 that convened experts from the Korey Stringer Institute (KSI), Uniformed Services University of the Health Sciences, Occupational Safety and Health Administration, National Institute for Occupational Safety and Health, and National Oceanic and Atmospheric Administration (NOAA). I would like to express special gratitude to Douglas J. Casa, PhD, ATC, Chief Executive Officer at the KSI, and Juli Trtanj, One Health & Integrated Climate and Weather Extremes Research Lead at the NOAA, for their support in convening the meeting and sharing the vision of interdisciplinary collaborations in advancing our research effort to optimize health and physical activity in the heat.

I would also like to acknowledge my coauthors for their time and dedication in creating this book. Their expertise in respective content area was invaluable.

Finally, I would like to take this opportunity to acknowledge the publishing team from Springer Nature for their assistance.

Yuri Hosokawa, PhD, ATC.
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Contents

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Chapter 1
Climate Change and Increasing Risk of Extreme Heat

Hunter M. Jones

Abstract Extreme heat has negative impacts on human health, labor productivity, and many other aspects of life. Both historical trends and future projections suggest that the extreme heat hazard will increase, but measures to reduce risk are being studied and implemented to lessen the impacts of extreme heat. Heat health early warning systems and longer-term planning and preparedness require skillful, seamless predictions of the heat hazard from weeks to months and from years to decades into the future. They allow for shorter-term interventions and longer-term policy and infrastructural investments which can reduce risk. Investments in observing systems, science to understand the physical mechanisms driving heat extremes, and model improvements are essential to developing these predictions and a critical part of addressing the human health risks of extreme heat in a changing climate.

Introduction

It is fitting that one of the most widely watched and venerated sporting events in the world, the Olympic Games, began as a tribute to Zeus, the Greek God of sky, thunder, and lightning. Atmospheric and other environmental conditions are critical factors to consider when planning and holding athletic events. Despite having made substantial progress in predicting atmospheric conditions since the first Olympic Games were held in 776 BC, weather has delayed or otherwise complicated events in many games, including the most recent – from heat and fog disrupting the Sochi Winter Olympics in 2014 [1] to rain disrupting the Rio Summer Olympics in 2016 [2].

Weather-induced logistical disruptions may be a nuisance for spectators and athletes and may have financial implications for host countries and sponsors, but weather-induced human health effects are an even more important consideration, as

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they can lead to great human suffering and death. Weather extremes can affect human health directly and indirectly in many ways – from creating ideal habitat for mosquitos and ticks that spread disease (a concern in Rio as Zika was spreading across many countries, including Brazil) to exacerbating poor air quality (a concern during the 2008 Summer Olympics in Beijing [3]) - but the direct effect of extreme heat on athletes can quickly cause a high exertion event such as a marathon to become deadly [4].

Widening the scope beyond athletics, the importance of considering the health implications of extreme heat becomes even clearer. According to the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS), the weather event that has caused the most fatalities in the United States, on average, over the past 30 years is extreme heat [5]. Moreover, the Centers for Disease Control and Prevention (CDC) has documented that of the 20 states that participated in their database, approximately 28,000 heat stress illness hospitalizations were reported during the decade spanning from May to September 2001–2010 [6]. During the period from 2005 to 2010, just half of that same decade, there were 98,462 heat stress illness emergency department visits in a sample of just 14 states [7]. These statistics demonstrate the dramatic effect of extreme heat on human health and a potentially large burden to the local medical system that may be overwhelmed during heat waves. In addition, extreme heat can catalyze degradation in air quality, reduce labor productivity, and induce psychological distress.

Extreme heat that can lead to these health impacts is often viewed as episodic, as is the case with heat waves, and is exemplified by time-limited increases in temperature (and in some cases additional confounding factors such as humidity) above what is normally experienced. However, heat waves are weather phenomena that take place within the larger context of climate norms, climate variability, and slowly evolving climate changes. Understanding the climate context of extreme heat is essential in understanding how the frequency, intensity, and other characteristics of extreme heat episodes have changed in the past and how they are likely to change in the future. This chapter examines the climatological context in which extreme heat affects human health.

Extreme Heat as a Meteorological Phenomenon

Heat is fundamentally a form of energy of molecular motion transferred between two systems, while temperature is a measure of the average energy of molecular motion in a system. This distinction is immediately important because temperature is a standard measure of heat and is how the distinction of "extreme" is made. It is the presence of a temperature gradient which results in a transfer of heat between two bodies.

This exchange of heat is occurring constantly within the Earth system's many components, especially the atmosphere and the oceans. In fact, this fundamental principle of thermodynamics[8] is a driving force behind the global circulation of the atmosphere and the ocean. Radiant energy from the sun falls unevenly on the Earth's surface – more at the equator and less at the poles – and the resultant warming of the Earth by this radiant energy creates a temperature gradient that runs from the equator poleward (North and South). This global imbalance is constantly being remedied by ocean currents and atmospheric winds, which to put in anthropocentric terms is Earth trying to achieve temperature equilibrium.

The redistribution of heat from the equator to the poles does not happen smoothly or evenly across the Earth. Due to a number of other physical science principles beyond the scope of this book, this redistribution of energy occurs via rapid and slow processes that are complex and chaotic. The resultant observations we make on Earth's surface are *weather*. In the atmosphere, large masses of air at different temperatures and pressures are constantly trying to reach equilibrium. At any given time, all across the globe, there is a patchwork of high- and low-pressure air masses in motion, generating a global circulation of air. Though chaotic, there are patterns and organized phenomena that can be observed, described, and predicted from our understanding of the underlying physics of the atmosphere. Heat waves are one such weather phenomenon.

The Anatomy of a Heat Wave

Though a variety of atmospheric conditions can lead to heat waves, a typical set-up for a heat wave occurs when a large mass of air in the atmosphere, at a relatively high temperature and pressure, lingers in the same place for a prolonged period of time (Fig. 1.1). The high pressure forms a cap that traps heat in place and prevents hot air at the surface of the Earth from rising as it normally would. This reduced

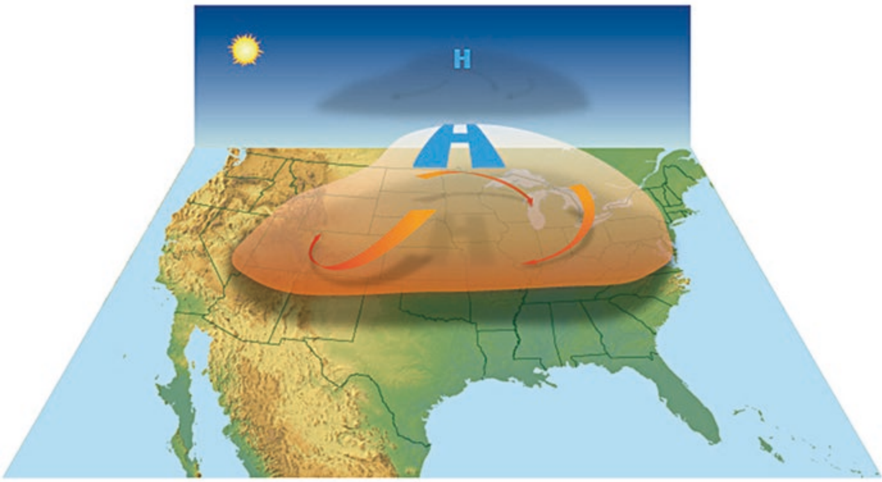

Fig. 1.1 Representation of the meteorological conditions driving a typical heat wave. A high-pressure system acts as a cap that traps hot air on the surface. Image from the National Oceanic and Atmospheric Administration (NOAA) http://www.srh.noaa.gov/jetstream/global/hi.htm (public domain)

convection, which could otherwise form clouds and ultimately rain reduces the cooling effect that would have otherwise occurred. Furthermore, the blocked air mass can cause stagnancy in airflow at the surface, again thwarting winds which could also have a cooling effect and potentially allowing air quality to degrade as criteria pollutants and other particles build up in the atmosphere [8].

A common reason for this stagnancy in airflow is an atmospheric block (or "blocking pattern"), which is a pattern of high- and low-pressure systems that become temporarily locked in place in a self-reinforcing configuration. A blocking pattern was a strong contributing factor [9] to the 2003 and 2010 heat waves in Europe that each claimed tens of thousands of lives [10, 11]. Furthermore, in the aforementioned cases of heat waves in Europe and in the Chicago heat wave of 1995, which took over 700 lives [12], moisture – or a lack thereof– contributed to both the intensity and lethality of the event [9, 13].

The European heat waves of 2003 and 2010 were both induced, in part, by soil moisture-temperature feedback, which is a type of evaporative cooling performed by soil moisture [9]. During extraordinarily dry conditions, the lack of moisture in the soil reduces evaporative cooling on a large scale and allows temperatures to soar, contributing to the intensity of heat waves. The opposite was the case during the Chicago heat wave of 1995 – which was coincident with normal to above-normal soil moisture levels. The moisture in the soil and consequent evaporation increased the dew point temperatures [14], allowing the air to retain more moisture and reducing the potential for evaporative cooling. The high dew points were likely influenced by changing agricultural practices in the region [15]. The heightened humidity of the air also reduced the potential for evaporative cooling from sweating and increased the heat index experienced by residents of Chicago.

Record-breaking heat waves, as extreme as those in Chicago in 1995 and Europe in 2003 and 2010, had been considered rare events, but they are becoming more frequent. In fact, the long-running historical trend for heat extremes indicates an increasing risk of more frequent, more intense, and longer-lasting extreme heat events across the United States [16]. This observed trend is predicted to continue into the future [17] and is driven, in part, by anthropogenic changes to the climate system [26]. How this is known, with what specificity and certainty, and the spatial and temporal variations in the realization of this trend are the charge of the climate science community.

Weather and Climate Extremes, Variability, and Change

A heat wave, by definition, is a multi-day phenomenon with a start and end date and is predicated upon the exceedence of defined thresholds of temperature (and possibly humidity and other parameters). Precisely what those parameters and thresholds (which can be absolute or relative) should be is an active area of research and discussion. Some operational definitions currently in use are based on maximum temperature, minimum temperature, average temperature, heat index (i.e., temperature